Certification of Translation

(Japanese Patent Application No. 11-258,089)

I, the undersigned, Sawako KODAMA residing at 1-25-5-204, Yutenji, Meguro-ku, Tokyo 153-0052, JAPAN do solemnly and sincerely declare that I am well acquainted with the Japanese language and the English language and that the attached English translation of the Japanese Patent Application No. 11-258,089 filed September 10, 1999 is an accurate translation to the best of my knowledge and belief from the Japanese language into the English language.

Date: March 9, 2006

Sawako Kodama

Sawako KODAMA

[DOCUMENT NAME] SPECIFICATION

[TITLE OF THE INVENTION]

LIGHT SOURCE UNIT AND EXPOSURE APPARATUS

[CLAIMS]

[CLAIM 1] A light source unit, said unit comprising:

a plurality of optical fibers;

a polarization adjustment unit which orderly arranges a polarized state of a plurality of light beams with the same wavelength having passed through said plurality of optical fibers; and

a polarized direction conversion unit which converts all light beams having passed through said plurality of optical fibers into a plurality of linearly polarized light beams that have the same polarized direction.

[CLAIM 2] The light source unit according to Claim 1, wherein

said polarization adjustment unit polarizes respectively said plurality of light beams having passed through each of said optical fibers into a state nearly circular, and

said polarized direction conversion unit has a quarter-wave plate.

[CLAIM 3] The light source unit according to Claim 2, wherein

said optical fibers have an almost cylindrical-symmetric structure; and

said polarization adjustment unit polarizes

respectively said plurality of light beams incident on each of said optical fibers into a state nearly circular.

[CLAIM 4] The light source unit according to Claim 1, wherein

said polarization adjustment unit polarizes respectively said plurality of light beams having passed through each of said optical fibers into an elliptic state almost identical, and

said polarized direction conversion unit has a half-wave plate that rotates a plane of polarization and a quarter-wave plate which is optically connected in series to said half-wave plate.

[CLAIM 5] The light source unit according to any one of Claims 1 to 4, wherein said plurality of optical fibers respectively are optical fibers making up an optical fiber amplifier, which amplifies a plurality of light beams subject to amplifying incident on said plurality of optical fibers, and waveguide said beams subject to amplifying.

[CLAIM 6] The light source unit according to any one of Claims 1 to 5, wherein said plurality of light beams incident on said plurality of optical fibers are respectively a pulse train.

[CLAIM 7] The light source unit according to any one of Claims 1 to 6, wherein said plurality of light beams incident on said plurality of optical fibers are respectively a light beam that has been amplified by at

least one stage of an optical fiber amplifier before entering said plurality of optical fibers.

[CLAIM 8] The light source unit according to any one of Claims 1 to 7, wherein said polarization adjustment unit performs polarization adjustment by controlling optical properties of optical components arranged on the optical path further upstream of said plurality of optical fibers.

[CLAIM 9] The light source unit according to any one of Claims 1 to 8, wherein said plurality of optical fibers are bundled almost in parallel.

[CLAIM 10] The light source unit according to any one of Claims 1 to 9, said light source unit further comprising a wavelength conversion unit which performs wavelength conversion on light beams emitted from said polarized direction conversion unit by said light beams passing through at least one nonlinear optical crystal.

[CLAIM 11] The light source unit according to Claim 10, wherein

light emitted from said plurality of optical fibers is light which wavelength is in one of an infrared and a visible region, and

light emitted from said wavelength conversion unit is light which wavelength is in an ultraviolet region.

[CLAIM 12] The light source unit according to Claim 11, wherein

said light emitted from said plurality of optical

fibers has a wavelength of around 1547nm, and

said light emitted from said wavelength conversion unit has a wavelength of around 193.4nm.

[CLAIM 13] An exposure apparatus which transfers a predetermined pattern onto a substrate by irradiating an exposure beam onto said substrate, said exposure apparatus comprising:

the light source unit according to one of Claims 11 and 12 as a generation unit of said exposure beam.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[RELEVANT TECHNICAL FIELD TO THE INVENTION]

The present invention relates to a light source unit and an exposure apparatus. More particularly, the present invention relates to a light source unit which emits a light having a desired wavelength while controlling polarization of a plurality of light beams, and an exposure apparatus comprising the light source unit.

[0002]

[RELATED ART]

Conventionally, in the lithographic process to manufacture a semiconductor device (integrated circuit), a liquid crystal display device, and the like, various exposure apparatus were used. In recent years, as these types of exposure apparatus, the reduction projection exposure apparatus such as the so-called stepper or the

so-called scanning stepper is mainstream, from the viewpoint of having high throughput. With the reduction projection exposure apparatus, a fine circuit pattern formed on a photomask or a reticle is reduced, projected, and transferred onto a substrate such as a wafer or a glass plate, which surface is coated with a photoresist via a projection optical system.

[0003]

However, the exposure apparatus such as the projection exposure apparatus require high resolution, along with high throughput. Using the wavelength of the illumination light for exposure λ and the numerical aperture of the projection optical system N.A., the resolution R, and the depth of focus DOF of the projection exposure apparatus are respectively expressed by:

$R = K \cdot \lambda / N.A.$ ······(1) and

$DOF = \lambda / 2(N.A.)^2$ ······(2).

[0004]

As is obvious from equation (1), three ways can be considered to obtain a smaller resolution R, that is, to decrease the minimum pattern line width that can be resolved; ① reduce the proportional constant K, ② increase the N.A., ③ reduce the wavelength of the illumination light for exposure λ. The proportional constant K, in this case, is a constant that is determined by the projection optical system or the

process, and is normally a value around 0.5 to 0.8. The method of decreasing the constant K is called super-resolution in a broad sense. Up until now, issues such as improvement of the projection optical system, modified illumination, phase shift reticle have been studied and proposed, however, there were drawbacks such as the patterns suitable for application being restricted.

[0005]

On the other hand, as can be seen from equation (1), the resolution R can be reduced by increasing the numerical aperture N.A., however, at the same time, this means that the depth of focus DOF is small, as is obvious from equation (2). Therefore, increasing the N.A. value has its limits, and normally, the appropriate value is around 0.5.

[0006]

Accordingly, the most simple and effective way of reducing the resolution R is to reduce the wavelength of the illumination light for exposure λ.

[0007]

For such reasons, conventionally, the g-line stepper and the i-line stepper that use an ultra-high pressure mercury lamp as the light source for exposure to emit the emission line (such as the g line or the i line) in the ultraviolet light region were mainly used, as the stepper or the like. However, in recent years, the KrF excimer laser stepper that uses a KrF excimer laser as the light

source to emit a KrF excimer laser beam having a shorter wavelength (wavelength: 248nm) is becoming mainstream. And currently, the exposure apparatus that uses the ArF excimer laser (wavelength: 193nm) as the light source having a shorter wavelength is under development. The excimer laser, however, has disadvantages as the light source for the exposure apparatus, such as, the size being large, the energy per pulse being large causing the optical components to damage easily, and the maintenance of the laser being complicated and expensive because of using poisonous fluorine gas.

[0008]

Therefore, the method of utilizing the nonlinear optics effect of the nonlinear optical crystal to convert light with a long wavelength (infrared light and visible light) to an ultraviolet light with a shorter wavelength and using the ultraviolet light as the exposure light, is gathering attention. As the light source for exposure employing this method, the array laser is disclosed in, for example, Japanese Patent Laid Open (Unexamined) No. 08-334803. An example of the array laser is disclosed, with which the wavelength of light from the laser beam generating portion comprising a semiconductor laser is converted by the nonlinear optical crystal arranged at the wavelength conversion portion, and a laser element which generates ultraviolet light is bundled into an ultraviolet light source of a plurality of lines in a

matrix shape (for example, 10x10).

[0009]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

With the array laser as described above, by bundling a plurality of lines of laser elements that are individually independent, the light emission of the individual laser elements can be suppressed at a low level, while maintaining the light emission of the whole apparatus high. However, since the individual laser elements were independent, fine adjustment was required in addition to an extremely complicated structure in order to make the oscillation spectrum of each laser element coincide with one another.

[0010]

And so, the method to convert the wavelength can be considered where the laser beam emitted from a single laser oscillation source is diverged, and the wavelength of each diverged beam is converted with a common nonlinear optical crystal after each diverged beam is amplified. In the case of employing this method, it is convenient to use optical fiber to guide the laser beam, and the arrangement of a plurality of bundled optical fibers emitting a plurality of beams incident on the nonlinear optical crystal is the most suitable from the viewpoint of simple arrangement, smaller diameter of the emitting beam, and maintenance operation.

[0011]

In addition, to efficiently generate a second harmonic and the like by the nonlinear optics effect using the nonlinear optical crystal, a linearly polarized beam of a specific direction which corresponds to the crystal direction of the nonlinear optical crystal needs to be incident on the nonlinear optical crystal. However, it is generally difficult to arrange the direction of the linearly polarized beams emitted from a plurality of optical fibers in order. This is because even if the polarization maintaining fiber is used to guide the linearly polarization, since the sectional shape of the optical fiber is almost round, the direction of the linearly polarization cannot be specified from the outside shape of the optical fiber.

[0012]

The present invention has been made in consideration of the situation described above, and has as its first object to provide a light source unit with a simple arrangement that can generate a predetermined light while controlling the polarized state.

[0013]

It is the second object of the present invention to provide an exposure apparatus that can efficiently transfer a predetermined pattern onto a substrate.

[0014]

[MEANS FOR SOLVING THE PROBLEMS]

A light source unit according to the present

invention is a light source unit comprising: a plurality of optical fibers; a polarization adjustment unit (16D) which orderly arranges a polarized state of a plurality of light beams with the same wavelength having passed through the plurality of optical fibers; and a polarized direction conversion unit (162) which converts all light beams having passed through the plurality of optical fibers into a plurality of linearly polarized light beams that have the same polarized direction.

[0015]

With the light source unit, a plurality of linearly polarized light beams that have the same polarized direction can be obtained in a simple arrangement, since the polarized direction conversion unit converts all light beams that have passed through the plurality of optical fibers into a plurality of linearly polarized light beams that have the same polarized direction, after the polarization adjustment unit orderly arranges the polarized state of a plurality of light beams emitted from the plurality of optical fibers.

[0016]

With the light source unit according to the present invention, in the case the polarization adjustment unit polarizes respectively the plurality of light beams having passed through each of the optical fibers into a state nearly circular, the polarized direction conversion unit can be structured to have a quarter-wave plate (162).

In such a case, the plurality of light beams having passed through each of the optical fibers are respectively circularly polarized, therefore, by making all the beams pass through the quarter-wave plate in the polarized direction conversion unit, the beams can be converted into linearly polarized light beams having the same polarized direction. Accordingly, a plurality of light beams can be converted into a plurality of linearly polarized light beams having the same polarized direction, while keeping the arrangement of the polarized direction conversion unit extremely simple, with one quarter-wave plate. The polarized direction of the linear polarization is determined by the direction of the optical axis of the crystal material and the like used to make the quarter-wave plate. Therefore, by adjusting the optical axis of the crystal material and the like used to make the quarter-wave plate, a plurality of light beams that have the same linearly polarized direction in an arbitrary direction can be obtained.

[0017]

In the case the optical fibers have an almost cylindrical-symmetric structure; the polarization adjustment unit can have the arrangement of polarizing respectively the plurality of light beams incident on each of the optical fibers into a state nearly circular. This is because in the case a circular polarized light is incident on an optical fiber having a cylindrical-

symmetric structure, then a circular polarized light is emitted from the optical fiber. Since it is not possible to structure the optical fiber in a complete cylindrical-symmetric structure, the length of the optical fiber is preferably shorter.

[0018]

In addition, with the light source unit according to the present invention, in the case the polarization adjustment unit polarizes respectively all the plurality of light beams having passed through each of the optical fibers into an arbitrary elliptic state almost identical, the polarized direction conversion unit can be structured to have a half-wave plate that rotates a plane of polarization and a quarter-wave plate which is optically connected in series to the half-wave plate. On optically connecting the half-wave plate and the quarter-wave plate in series, either of them may be arranged upstream of the optical path. For example, in the case the half-wave plate is arranged on the upper side of the optical path, the plurality of light beams having passed through each optical fiber pass through the common half-wave plate, and the planes of polarization of the plurality of light beams are identically rotated. And after the planes of polarization are identically rotated, the plurality of light beams proceed through the common quarter-wave plate, thus, the light beams are all linearly polarized to have the same polarized direction. Also, in the case the

quarter-wave plate is arranged upstream of the optical path, the light beams can all be linearly polarized to have the same polarized direction, likewise with the case when the half-wave plate is arranged upstream. Accordingly, the polarized direction conversion unit can have a simple arrangement, of a half-wave plate and a quarter-wave plate. In this case, by adjusting the optical axis of the crystal material and the like used to make the half-wave plate and the quarter-wave plate, a plurality of light beams that have the same linearly polarized direction in an arbitrary direction can be obtained.

[0019]

In addition, with the fifth light source unit according to the present invention, the light source unit can have the structure of the plurality of optical fibers respectively being optical fibers making up an optical fiber amplifier (171), which amplifies a plurality of light beams subject to amplifying incident on the plurality of optical fibers, and waveguide the beams subject to amplifying. In such a case, since light incident on each optical fiber is respectively amplified and emitted from each optical fiber, the emitted light each has high intensity and a plurality of linearly polarized light beams having the same polarized direction can be obtained as the emitted light from the polarized direction conversion unit. As a result, the light amount

of the emitted light can be increased in the light source unit as a whole.

[0020]

With the light source unit according to the present invention, the plurality of light beams incident on the plurality of optical fibers can respectively be a pulse train. In such a case, by adjusting the repetition frequency of the light pulse or the pulse height in each pulse train, the light amount of the emitted light can be controlled with high precision in the light source unit as a whole.

[0021]

In addition, with the light source unit according to the present invention, the plurality of light beams incident on the plurality of optical fibers can respectively be a light beam that has been amplified by at least one stage of an optical fiber amplifier (167) before entering the plurality of optical fibers. In such a cases, by the light amplification of one or more stages of the optical fiber amplifiers, the light amount of the emitted light can be increased in the light source unit as a whole.

[0022]

In addition, with the light source unit according to the present invention, the polarization adjustment unit can adjust the polarized state of the plurality light beams incident on the polarized direction conversion unit

by adjusting the mechanical stress and the like respectively impressed on the plurality of optical fibers arranged before the polarized direction conversion unit. The polarization adjustment unit can also have the arrangement of performing polarization adjustment by controlling optical properties of optical components arranged on the optical path further upstream of the plurality of optical fibers. In such a case, the plurality of optical fibers arranged immediately before the polarized direction conversion unit are optical fibers that have light amplifying portions and light subject to amplification are wave-guided to the optical fibers. And, even in the case the polarization adjustment of impressing stress and the like on the optical fibers is not adequate, by controlling the optical properties of the optical components arranged further upstream on the optical path which polarization adjustment can be made easier, the polarized state of the plurality of light beams incident on the polarized direction conversion unit can be arranged in an orderly manner.

[0023]

In addition, with the light source unit according to the present invention, the plurality of optical fibers may have the structure of being bundled almost in parallel to one another. In such a case, the section where the plurality of optical fibers occupy can be made small, as well as reduce the photo-detecting area of the

polarized direction conversion unit. Therefore, the size of the light source can be reduced.

[0024]

Further, with the light source unit according to the present invention, the light source unit can have the arrangement of further comprising a wavelength conversion unit (163) which performs wavelength conversion on light beams emitted from the polarized direction conversion unit by the light beams passing through at least one nonlinear optical crystal. In such a case, by setting the polarized direction of the light beams emitted from the polarized direction conversion unit to the polarized direction on which the wavelength of the incident light is effectively converted (double harmonic generation, sum frequency generation) by the nonlinear optical crystal, light which wavelength has been effectively converted can be generated and emitted.

[0025]

The light emitted from the plurality of optical fibers can have a wavelength, which is in one of an infrared and a visible region, and light emitted from the wavelength conversion unit can have a wavelength in the ultraviolet region. In such a case, an ultraviolet light suitable for transferring a finer pattern can be effectively generated.

[0026]

In this case, the light emitted from the plurality of

optical fibers can have a wavelength of around 1547nm, and the light emitted from the wavelength conversion unit can have a wavelength of around 193.4nm. In such a case, light having the wavelength when the ArF excimer laser light source is used can be effectively obtained.

[0027]

An exposure apparatus according to the present invention is an exposure apparatus which transfers a predetermined pattern onto a substrate (W) by irradiating an exposure beam onto the substrate, the exposure apparatus comprising: the light source unit (16) according to the present invention as a generation unit of the exposure beam, in which a wavelength conversion unit generates an ultraviolet light.

[0028]

With the exposure apparatus, since the light source unit that efficiently generates ultraviolet light suitable for transferring fine patterns is used, the predetermined pattern can be efficiently transferred onto the substrate.

[0029]

[EMBODIMENT OF THE INVENTION]

An embodiment of the present invention will be described below with reference to Figs. 1 to 6.

[0030]

Fig. 1 shows the schematic view of the exposure apparatus 10 related to the embodiment, which structure

includes the light source unit related to the present invention. The exposure apparatus 10 is a scanning type exposure apparatus based on the step-and-scan method.

[0031]

The exposure apparatus 10 comprises: an illumination system consisting of a light source unit 16 and an illumination optical system 12; a reticle stage RST that holds a reticle R serving as a mask which is illuminated by the illumination light for exposure (hereinafter referred to as "exposure light") IL from the illumination system; a projection optical system PL which projects the exposure light IL outgoing from the reticle R onto a wafer W serving as a substrate; an XY stage 14 on which a Z tilt stage 58 serving as a substrate stage holding the wafer W is mounted; control systems for these parts; and the like.

[0032]

The light source unit 16 is, for example, a harmonic generation unit that emits an ultraviolet pulse light having a wavelength of 193nm (almost the same wavelength as of the ArF excimer laser beam) or an ultraviolet pulse light having a wavelength of 157nm (almost the same wavelength as of the F_2 laser beam). The light source unit 16 is housed within an environmental chamber (hereinafter referred to as "chamber") 11 where the temperature, pressure, humidity, and the like are adjusted with high precision. In the environmental

chamber 11, the illumination optical system 12, the reticle stage RST, the projection optical system PL, the Z tilt stage 58, the XY stage 14, and a main body of the exposure apparatus consisting of a main column (not shown in Figs.) on which these parts are arranged, are also housed.

[0033]

Fig. 2 is a block diagram showing the internal structure of the light source unit 16 along with the main controller 50, which performs overall control over the entire exposure apparatus. As is shown in Fig. 2, the light source unit 16 is structured to include a light source portion 16A, a laser controller 16B, a light amount controller 16C, a polarization adjustment unit 16D, and the like.

[0034]

The light source portion 16A has a structure including a pulse light generation portion 160 serving as a light generation portion, a light amplifying portion 161, a quarter-wave plate 162 serving as a polarized direction conversion unit, a wavelength conversion portion 163, a beam monitor mechanism 164, an absorption cell 165, and the like.

[0035]

The pulse light generation portion 160 has a laser light source 160A, photocoupler BS1 and BS2, optical isolator 160B, an electro-optic modulator (hereinafter

referred to as "EOM") 160C serving as an optical modulator, and the like. And, each element arranged in between the laser light source 160A and the wavelength conversion portion 163 is optically connected to one another by optical fiber.

[0036]

As the laser light source 160A, in this case, a single wavelength oscillation laser is used, for example, an InGaAsP DFB semiconductor laser, which has an oscillation wavelength of 1.544μm, continuous-wave output (hereinafter referred to as "CW output") of 20mW, is used. Hereinafter in this description, the laser light source 160A will be referred to as "DFB semiconductor laser 160A", as appropriate.

[0037]

DFB semiconductor laser, in this description, is a diffraction grating made within the semiconductor laser, instead of the Fabry-Perot resonator having low longitudinal mode selectivity, and is structured to oscillate a single longitudinal mode in any circumstances. It is called the distributed feedback (DFB) laser, and since this type of laser basically performs a single longitudinal mode oscillation, the oscillation spectral line width can be suppressed so that it does not exceed 0.01pm.

[0038]

In addition, the DFB semiconductor laser is usually

arranged on a heatsink, and these are housed in a casing. With the embodiment, a temperature adjustment unit (for example, a Peltier element) is arranged on the heatsink of the DFB semiconductor laser 160A, and as will be described later on, the embodiment has a structure so that the laser controller 16B is capable of controlling (adjusting) the oscillation wavelength by controlling the temperature of the temperature adjustment unit.

[0039]

That is, the temperature dependence of the oscillation wavelength of the DFB semiconductor laser is around 0.1nm/°C. Accordingly, if the temperature of the DFB semiconductor laser changes 1°C, the wavelength of the reference wave (1544nm) changes 0.1nm. So, in the case of an eighth-harmonic wave (193nm) the wavelength changes 0.0125nm, and in the case of a tenth-harmonic wave (157nm) the wavelength changes 0.01nm.

[0040]

With the exposure apparatus, it is sufficient enough if the wavelength of the illumination light for exposure (pulse light) varies around ±20pm in respect to the center wavelength. Accordingly, in the case of the eighth-harmonic wave the temperature of the DFB semiconductor laser 11 needs to vary around ±1.6°C, and in the case of the tenth-harmonic wave the temperature needs to vary around ±2°C.

[0041]

The laser light source 160A is not limited to semiconductor lasers such as the DFB semiconductor laser. For example, the ytteribium (Yb) doped fiber laser which has an oscillation wavelength of around 990nm can be used.

[0042]

The photocoupler BS1 and BS2 have a transmittance of around 97%. Therefore, the laser beam from the DFB semiconductor laser 160A is separated into two beams at the photocoupler BS1, and around 97% of the separated beam proceeds toward the photocoupler BS2 at the next stage, whereas, the remaining 3% is incident on the beam monitor mechanism 164. Furthermore, the laser beam incident on the photocoupler BS2 is separated, and around 97% of the separated beam proceeds to the optical isolator 160B, whereas, the remaining 3% is incident on the absorption cell 165.

[0043]

The beam monitor mechanism 164, the absorption cell 165, and the like will be described in detail later on in the description.

[0044]

The optical isolator 160B is a device, which allows only light proceeding from the photocoupler BS2 to the EOM160C to pass, and prevents light proceeding in the opposite direction from passing. The optical isolator 160B prevents the oscillation mode of the DFB semiconductor laser 160A from changing or noise from

being generated, which are caused by the reflecting light (returning light).

[0045]

The EOM160C is a device, which converts the laser beam (CW beam (continuous-wave beam) that has passed through the optical isolator 160B into a pulse light. As the EOM160C, an electrooptical modulator (for example, a double-electrode modulator) that has an electrode structure having performed chirp correction is used, so that the wavelength broadening of the semiconductor laser output by chirp due to temporal change in the refractive index is decreased. The EOM160C emits a pulse light modulated in synchronous with the voltage pulse impressed from the light amount controller 16C. For example, if the EOM160C modulates the laser beam oscillated from the DFB semiconductor laser 160A into a pulse light with a pulse width of 1ns and a repetition frequency of 100kHz (pulse period around 10μs), as a result of this optical modulation, the peak output of the pulse light emitted from the EOM160 is 20mW, and the average output 2μW. In this case, the insertion of the EOM160C does not create any loss, however, in the case there is a loss by insertion, for example, when the loss is -3dB, the peak output of the pulse light becomes 10mW, and the average output 1μW.

[0046]

In the case of setting the repetition frequency to

around 100kHz and over, it is preferable to prevent the amplification reduction due to the noise effect of the ASE (Amplified Spontaneous Emission) with the fiber amplifier. The details on this will be described later on in the description.

[0047]

When only the EOM160C is used and the pulse light is turned off, in the case the extinction ratio is not sufficient enough, it is preferable to use the current control of the DFB semiconductor laser 160A. That is, since with semiconductor lasers and the like, the emitted light can be pulse oscillated by performing current control, it is preferable to generate the pulse light by utilizing both the current control of the DFB semiconductor laser 160A and the EOM160C. For example, if a pulse light having a width of around 10 - 20 ns is oscillated by the current control of the DFB semiconductor laser 160A and is partially extracted and modulated by the EOM160C into a pulse light having a width of around 1ns, it becomes possible to generate a pulse light that has a narrow pulse width compared with the case when using only the EOM160C, and can also further simplify the control of the oscillation interval and the beginning/end of the oscillation of the pulse light.

[0048]

Alternately, it is possible to use an acousto-optic

modulator (AOM) instead of the EOM160C.

[0049]

The light amplifying portion 161 amplifies the pulse light from the EOM160C, and in this case, is structured including a plurality of fiber amplifiers. An example of the arrangement of the light-amplifying portion 161 is shown in Fig. 3 with the EOM160C.

[0050]

As shown in Fig. 3, the light amplifying portion 161 comprises: a delay portion 167, which has a total of 128 channels from 0 to 127; fiber amplifiers 168_1 - 168_{128} which are respectively connected to the output side of the channels 0 to 127 (a total of 128 channels) of the delay portion 167; narrow-band filters 169_1 - 169_{128}, optical isolators 170_1 - 170_{128}, fiber amplifiers 171_1 - 171_{128}, which are connected to the output side of the fiber amplifiers 168_1 - 168_{128} in this order, and the like. In this case, as is obvious from Fig. 3, the fiber amplifier 168_n, the narrow-band filter 169_n, the optical isolator 170_n, and the fiber amplifier 171_n (n=1, 2, ..., 128) respectively make up the optical path 172_n (n=1, 2, ..., 128).

[0051]

To further describe each structuring portion of the light amplifying portion 161, the delay portion 167 has a total of 128 channels, and provides a predetermined delay time (in this case 3ns) to the output of each channel. In

this embodiment, the structure of the delay portion 167 includes: an erbium (Er)-doped fiber amplifier (EDFA), which performs a 35dB (x 3162) optical amplification on the pulse light emitted from the EOM160C; a splitter (1 planar waveguide x 4 splitters) serving as an optical branch unit which divides in parallel the output of the EDFA into four (channels 0 to 3) outputs; four optical fibers with different lengths, which are respectively connected to the output end of the channels 0 to 3 of the splitter; four splitters (1 planar waveguide x 32 splitters) which divides the output of the four optical fibers respectively into 32 (channels 0 to 31); and 31 optical fibers each (a total of 124 optical fibers) having different lengths, which are respectively connected to the channels 1 to 31 (excluding channel 0) of each splitter. Hereinafter, the channels 0 to 31 of each splitter (1 planar waveguide x 32 splitters) will be referred to as a "block" in general.

[0052]

More particularly, the pulse light emitted from the EDFA has a peak output of around 63W, and the average output is around 6.3W. This pulse light is divided in parallel into four outputs, to channel 0 to 3 by the splitter (1 planar waveguide x 4 splitters), and a delay corresponding to the length of the four optical fibers is provided to the light emitted from each channel. For example, in the embodiment, when the propagation velocity

of light in the optical fiber is 2 x 10^8m/s, and the length of the optical fibers connected to the channels 0, 1, 2, and 3 of the splitter (1 planar waveguide x 4 splitters) are 0.1m, 19.3m, 38.5m, and 57.7m respectively (hereinafter referred to as the "first delay fiber"), then the delay of light between adjacent channels at the emitting side of the first delay fiber is 96ns.

[0053]

In addition, to the channels 1 to 31 of the four splitters (1 splitter: 1 planar waveguide x 32 splitters), optical fibers (hereinafter referred to as the "second delay fiber") respectively having the length of 0.6 x N (N = channel number) are connected. As a consequence, a delay of 3ns is provided between adjacent channels within each block. And in respect to the output of channel 0 in each block, a delay of 3x31=93ns is provided to the output of channel 31.

[0054]

Meanwhile, in between each block, from the first block to the fourth block, the first delay fiber respectively provides a delay of 96ns at the input stage of each block, as is described above. Accordingly, the channel 0 output of the second block is provided a delay of 96ns in respect to the channel 0 output of the first block, and a delay of 3ns in respect to the channel 31 output of the first block. This is likewise, between the second and third block, and the third and fourth block.

And as a consequence, as the entire output, on the emitting side of the 128 channels, a pulse light that has a 3ns delay in between adjacent channels can be obtained.

[0055]

From the branch and delay described above, on the emitting side of the 128 channels, the pulse light that has a 3ns delay in between adjacent channels is obtained, and the light pulse that can be observed at each emitting end is 100kHz (pulse period 10μs), which is the same as the pulse modulated by the EOM 160C. Accordingly, from the viewpoint of the entire laser beam generating portion, the repetition of the next pulse train being generated at an interval of 9.62μs after 128 pulses are generated at an interval of 3ns, is performed at 100kHz. That is, the total output becomes $128 \times 100 \times 10^3 = 1.28 \times 10^7$ pulse/second.

[0056]

With the embodiment, the example was of the case when the channel was divided into 128 and the delay fibers used were short, thus, in between pulse trains an interval of 9.62μs occurred where no light was emitted. However, by increasing the number of divided channels, or by using a longer delay fiber with an appropriate length, or by combining both methods, it is possible to make the pulse interval completely equal.

[0057]

In the embodiment, the erbium (Er)-doped fiber amplifier (EDFA) which mode field diameter of the optical

fiber (hereinafter referred to as "mode diameter") is 5 - 6μm, likewise with the optical fiber normally used for communication, is used as the fiber amplifier 168_n (n=1, 2, ..., 128). The fiber amplifier 168_n amplifies the emitted light from each channel of the delay portion 167 according to a predetermined amplifier gain. The pumped light source and the like of the fiber amplifier 168_n will be described later in the description.

[0058]

The narrow-band filter 169_n (n=1, 2, ..., 128) cuts the ASE generated at the fiber amplifier 168_n while allowing the output wavelength (wavelength width around 1pm or under) of the DFB semiconductor laser 160A to pass, so that the wavelength width of the light transmitted is substantially narrowed. This can prevent the amplifier gain being reduced by the ASE being incident on the fiber amplifier 171_n arranged on the output side, or the laser beam from scattering due to traveling the noise of the ASE. It is preferable for the narrow-band filter 169_n to have a transmission wavelength width of around 1pm, however, since the wavelength width of the ASE is around several tens (nm) the ASE can be cut with the current narrow-band filter having the transmission wavelength width of around 100pm to an extent so that there are substantially no serious problems.

[0059]

In addition, in the embodiment, since there are cases

when the output wavelength of the DFB semiconductor laser 160A is positively changed, as will be described later, it is preferable to use a narrow-band filter that has a transmission wavelength width (the same level or above the variable width) in accordance with the variable width of the output wavelength (the variable width of the exposure apparatus in the embodiment is, for example, around ±20pm). With the laser unit applied in the exposure apparatus, the wavelength width is set around 1pm and under.

[0060]

The optical isolator 170_n (n=1, 2, ..., 128) reduces the effect of the returning light, likewise with the optical isolator 160B described earlier.

[0061]

As the fiber amplifier 171_n (n=1, 2, ..., 128), in the embodiment, in order to avoid the spectral width of the amplified light from increasing due to the nonlinear effect in the optical fiber, the mode diameter of the optical fiber used is wider than the optical fiber normally used for communication (5 - 6μm). For example, an EDFA with a wide diameter of around 20 - 30μm is used. The fiber amplifier 171_n further amplifies the light emitted from each channel of the delay portion 167 that have already been amplified with the fiber amplifier 168_n. As an example, when the average output of each channel of the delay portion 167 is around 50μW and the average

output of all the channels is around 6.3mW, and an amplification of a total of 46dB (x 40600) is performed by the fiber amplifier 168_n and the fiber amplifier 171_n, at the output end of the optical path 172_n corresponding to each channel (the output end of the optical fiber making up the fiber amplifier 171_n), the peak output of 20kW, the pulse width 1ns, the pulse repetition frequency 100kHz, the average output 2W, and the average output of all the channels in total 256W are obtained. The pumped light source and the like of the fiber amplifier 171_n will also be described later in the description.

[0062]

In the embodiment, the output end of the optical path 172_n corresponding to each channel of the delay portion 167, that is, the output end of the optical fiber making up the fiber amplifier 171_n, is bundled to form a fiber-bundle 173, which has a sectional shape as is shown in Fig. 4. The cladding diameter of each optical fiber is around 125μm, therefore, the diameter of the bundle of 128 optical fibers at the output end can be around 2mm or under. In the embodiment, the fiber-bundle 173 is formed using the output end of the fiber amplifier 171_n itself, however, a non-doped optical fiber can be connected to each output end of the fiber amplifier 171_n and the bundle-fiber can be formed by bundling these optical fibers.

[0063]

The fiber amplifier 168_n that has an average mode diameter and the fiber amplifier 171_n that has a wide mode diameter are connected using an optical fiber which mode diameter increases in the shape of a truncated cone.

[0064]

Next, the pumped light source and the like of each fiber amplifier are described with reference to Fig. 5. Fig. 5 schematically shows the fiber amplifiers and their neighboring area structuring the light amplifying portion 161, with a partial view of the wavelength conversion portion 163.

[0065]

In Fig. 5, a semiconductor laser 178 for pumping is fiber coupled to the fiber amplifier 168_n, and the output of the semiconductor laser 178 is input into the doped fiber for the fiber amplifier through the wavelength division multiplexer (WDM) 179. The doped fiber is pumped with this operation.

[0066]

Meanwhile, with the fiber amplifier 171_n having a wide mode diameter, a semiconductor laser 174 that serves as a pumping light source to pump the doped fiber for the fiber amplifier having a wide mode diameter is fiber coupled to the fiber with the wide mode diameter, which diameter matches that of the doped fiber for the fiber amplifier. And the output of the semiconductor laser 174 is input to the doped fiber for the optical amplifier

using the WDM 176, and thus the doped fiber is pumped.

[0067]

The laser beam amplified with the wide mode diameter (fiber amplifier) 171_n is incident on the wavelength conversion portion 163, and the wavelength of the laser beam is converted to generate the ultraviolet laser beam. The arrangement of the wavelength conversion portion and the like will be described, later in the description.

[0068]

It is preferable for the laser beam (signals) transmitted through the wide mode diameter (fiber amplifier) 171_n to be mainly in the fundamental mode, and this can be achieved by selectively pumping the fundamental mode in a single mode or multimode fiber with a low mode order.

[0069]

With the embodiment, four high-powered semiconductor lasers are fiber coupled to the wide mode diameter fiber in both the proceeding direction of the laser beam (signals) and the direction opposite. In this case, in order to effectively couple the semiconductor laser beam for pumping to the doped fiber for optical amplification, it is preferable to use an optical fiber which cladding has a double structure as the doped fiber for optical amplification,. And, the semiconductor laser beam for pumping is guided into the inner cladding of the dual cladding by the WDM 176.

[0070]

The semiconductor lasers 178 and 174 are controlled by the light amount controller 16C.

[0071]

In addition, in the embodiment, since the fiber amplifiers 168_n and 171_n are provided as the optical fiber making up the optical path 172_n, the gain difference in each fiber amplifier becomes the dispersion of the light emitted at each channel. Therefore, in the embodiment, the output is partially branched at the fiber amplifier of each channel (168_n and 171_n) and is photo-electrically converted by the photoconversion elements 180 and 181 arranged respectively at the branched end. And the output signals of these photoconversion elements 180 and 181 are sent to the light amount controller 16C.

[0072]

The light amount controller 16C feedback controls the drive current of each pumping semiconductor laser (178 and 174) so that the light emitted from each fiber amplifier is constant (that is, balanced) at each amplifying stage.

[0073]

Furthermore, with the embodiment, as is shown in Fig. 5, the laser beam split by the beam splitter halfway through the wavelength conversion portion 163 is photo-electrically converted by the photoconversion element 182, and the output signal of the photoconversion element 182

is sent to the light amount controller 16C. The light amount controller 16C then monitors the light intensity of the wavelength conversion portion 163 based on the output signals of the photoconversion element 182, and feedback controls the drive current of at least either the pumping semiconductor laser 178 or the pumping semiconductor laser 174 so that the light output from the wavelength conversion portion 163 becomes a predetermined light output.

[0074]

By having this arrangement, since the amplification of the fiber amplifier in each channel is constant at each amplifying stage, a unified light intensity can be obtained as a whole without an overload on either fiber amplifier. In addition, by monitoring the light intensity of the wavelength conversion portion 163, the expected predetermined light intensity can be fed back to each amplifier, and the desired ultraviolet light output can be stably obtained.

[0075]

Details on the light amount controller 16C will be described later in the description.

[0076]

From the light amplifying portion 161 (the output side of each optical fiber forming the bundle-fiber 173) having the arrangement described above, the pulse light is emitted, on which circular polarization has been

performed by the polarization adjustment unit 16D which will be described later. The circular polarized pulse light is converted to a linear polarized pulse light where the polarized direction is all the same by the quarter-wave plate 162 (refer to Fig. 2), and is then incident on the wavelength conversion portion 163.

[0077]

The wavelength conversion portion 163 includes a plurality of nonlinear optical crystals, and converts the wavelength of the amplified pulse light (light having the wavelength of 1.544μm) into an eighth-harmonic wave or a tenth-harmonic wave so that ultraviolet light that has the same output wavelength as the ArF excimer laser (wavelength: 193nm) is generated.

[0078]

Fig. 6 shows examples of the arrangement of the wavelength conversion portion 163. Following is a description of a concrete example on the wavelength conversion portion 163, with reference to this Figure. Fig. 6 shows an example of the arrangement when ultraviolet light having the same wavelength as the ArF excimer laser (193nm) is generated by converting the fundamental wave of the wavelength 1.544μm output from the emitting end of the fiber-bundle 173 using the nonlinear optical crystal into an eighth-harmonic wave.

[0079]

At the wavelength conversion portion 163 in Fig. 6,

the wavelength conversion is performed in the order of: fundamental wave (wavelength: 1.544μm) → second-harmonic wave (wavelength: 772nm) → third-harmonic wave (wavelength: 515nm) → fourth-harmonic wave (wavelength: 386nm) → seventh-harmonic wave (wavelength: 221nm) → eighth-harmonic wave (wavelength: 193nm).

[0080]

More particularly, the fundamental wave output from the emitting end of the fiber-bundle 173 that has the wavelength of 1.544μm (frequency ω) is incident on the first stage nonlinear optical crystal 533. When the fundamental wave passes through the nonlinear optical crystal 533, by the second-harmonic generation a second-harmonic wave which frequency is doubled from the frequency ω of the fundamental wave, that is, a second-harmonic wave with a frequency of 2ω (the wavelength is half, which is 772nm) is generated. In the case of Fig. 6A, the linear polarization by the quarter-wave plate 162 is performed so that the polarized direction is set in the direction where the second-harmonic wave is generated most efficiently. Such polarized direction setting of the linear polarization is performed, by adjusting the direction of the optical axis of the quarter-wave plate 162.

[0081]

As the first stage nonlinear optical crystal 533, an LiB_3O_5(LBO) crystal is used, and NCPM (Non-Critical Phase

Matching), which is a method of adjusting the temperature of the LBO crystal for phase matching to convert the wavelength of the fundamental wave to a second-harmonic wave, is employed. NCPM is capable of converting the fundamental wave into a second-harmonic wave with high efficiency, since walk-off between the fundamental wave and the second-harmonic wave does not occur within the nonlinear optical crystal, and also because of the advantage that the beam shape of the second-harmonic wave generated does not change by the walk-off.

[0082]

The fundamental wave that has passed through the nonlinear optical crystal 533 without the wavelength converted and the second-harmonic wave generated by the wavelength conversion are respectively provided a delay of a half wave and a single wave at a wavelength plate 534 at the next stage. Only the fundamental wave rotates the polarized direction by 90 degrees, then the fundamental wave and the second-harmonic wave are incident on the second stage nonlinear optical crystal 536. As the second nonlinear optical crystal 536, an LBO crystal is used, and the LBO crystal is used in NCPM at a temperature different from the first nonlinear optical crystal (LBO crystal) 533. In the nonlinear optical crystal 536, a third-harmonic wave (wavelength: 515nm) is generated by sum frequency generation of the second-harmonic wave generated in the first nonlinear optical

crystal 533 and of the fundamental wave that has passed through the nonlinear optical crystal 533 without the wavelength converted.

[0083]

Then, the third-harmonic wave obtained in the nonlinear optical crystal 536 and the fundamental wave and the second-harmonic wave that have passed through the nonlinear optical crystal 536 without being converted are separated at the dichroic mirror 537, and the third-harmonic wave reflected on the dichroic mirror 537 passes through the condenser lens 540 and the dichroic mirror 543 and is incident on the fourth stage nonlinear optical crystal 545. Meanwhile, the fundamental wave and the second-harmonic wave that have passed through the dichroic mirror 537 passes through a condenser lens 538 and are incident on the third stage nonlinear optical crystal 539.

[0084]

The LBO crystal is used as the third stage nonlinear optical crystal 539, and the fundamental wave passes through the LBO crystal without being converted, whereas, the second-harmonic wave is converted to a fourth-harmonic wave (wavelength: 386nm) by second-harmonic generation. The fourth-harmonic wave obtained in the third nonlinear optical crystal 539 and the fundamental wave that has passed through the third nonlinear optical crystal 539 are separated at the dichroic mirror 541, and

the fundamental wave that has passed through the dichroic mirror 541 passes through the condenser lens 544 and is reflected on the dichroic mirror 546, and is incident on the fifth stage nonlinear optical crystal 548. On the other hand, the fourth-harmonic wave reflected on the dichroic mirror 541 passes through the condenser lens 542 and reaches the dichroic mirror 543, and is coaxially synthesized with the third-harmonic wave reflected on the dichroic mirror 537 and then is incident on the fourth stage nonlinear optical crystal 545.

[0085]

As the fourth stage nonlinear optical crystal 545, a β-BaB_2O_4(BBO) crystal is used, and a seventh-harmonic wave (wavelength: 221nm) is generated by sum frequency generation of the third -harmonic wave and the fourth-harmonic wave. The seventh-harmonic wave generated in the fourth nonlinear optical crystal 545 passes through the condenser lens 547, and is coaxially synthesized with fundamental wave that has passed through the dichroic mirror 541 at the dichroic mirror 546, and is then incident on the fifth stage nonlinear optical crystal 548.

[0086]

As the fifth stage nonlinear optical crystal 548, the LBO crystal is used, and an eighth-harmonic wave (wavelength: 193nm) is generated by sum frequency generation of the fundamental wave and the seventh-harmonic wave. In the arrangement above, instead of the

BBO crystal 545 used to generate the seventh-harmonic wave and the LBO crystal 548 used to generate the eight-harmonic wave, it is also possible to use a $CsLiB_6O_{10}$ (CLBO) crystal and a $Li_2B_4O_7$ (LB4) crystal.

[0087]

With the arrangement example in Fig. 6, since the third-harmonic wave and the fourth-harmonic wave proceed through different optical paths and are incident on the fourth stage nonlinear optical crystal 545, the lens 540 to condense the third-harmonic wave and the lens 542 to condense the fourth-harmonic wave can be arranged on separate optical paths. The sectional shape of the fourth-harmonic wave generated in the third nonlinear optical crystal 539 is elliptic due to the walk-off phenomenon. Therefore, in order to obtain favorable conversion efficiency in the fourth stage nonlinear optical crystal 545, it is preferable to perform beam shaping on the fourth-harmonic wave. In this case, since the condenser lens 540 and 542 are arranged on different optical paths, for example, a pair of cylindrical lens can be used as the lens 542 to easily perform beam shaping on the fourth-harmonic wave. This makes it possible for the fourth-harmonic wave to overlap the third-harmonic wave favorably at the fourth stage nonlinear optical crystal 545, and the conversion efficiency can be increased.

[0088]

Furthermore, the lens 544 to condense the fundamental wave incident on the fifth stage nonlinear optical crystal 548 and the lens 547 to condense the seventh-harmonic wave can be arranged on different optical paths. The sectional shape of seventh-harmonic wave generated in the fourth stage nonlinear optical crystal 545 is elliptic due to the walk-off phenomenon. Therefore, in order to obtain favorable conversion efficiency in the fifth stage nonlinear optical crystal 548, it is preferable to perform beam shaping on the seventh-harmonic wave. In the embodiment, since the condenser lens 544 and 547 can be arranged on different optical paths, for example, a pair of cylindrical lens can be used as the lens 547 to easily perform beam shaping on the seventh-harmonic wave. Thus, the seventh-harmonic wave can favorably overlap the fundamental wave at the fifth stage nonlinear optical crystal (LBO crystal) 548, and the conversion efficiency can be increased.

[0089]

The structure in between the second stage nonlinear optical crystal 536 and the fourth stage nonlinear optical crystal 545 is not limited to the arrangement shown in Fig. 6. It can have any arrangement, so long as the third-harmonic wave, generated in the nonlinear optical crystal 536 and reflected on the dichroic mirror 537, and the fourth-harmonic wave, obtained by converting the wavelength of the second-harmonic wave generated in

the nonlinear optical crystal 536 which passes through the dichroic mirror 537 in the nonlinear optical crystal 539, are both incident at the same time on the nonlinear optical crystal 545, and the length of the optical paths in between both nonlinear optical crystals 536 and 545 is equal. The same can be said of the structure in between the third stage nonlinear optical crystal 539 and the fifth stage nonlinear optical crystal 548.

[0090]

According to an experiment performed by the inventor, in the case of Fig. 6, the average output of the eighth-harmonic wave (wavelength: 193nm) in each channel was around 45.9mW. Accordingly, the average output of the bundle of the entire 128 channels becomes 5.9W, therefore, ultraviolet light having a wavelength of 193nm can be provided, which is sufficient enough as an output of a light source for an exposure apparatus.

[0091]

In this case, on generating an eighth-harmonic wave (wavelength: 193nm), currently, the LBO crystal, which has good quality and can be purchased easily on the market, is used. Since the LBO crystal has an extremely small absorption coefficient to the ultraviolet light having a wavelength of 193nm, and the optical damage of the crystal does not create a serious problem, the LBO crystal is advantageous in durability.

[0092]

In addition, at the generating portion of the eighth-harmonic wave (wavelength: 193nm), angular phase matching is performed on the LBO crystal used, however, since the phase matching angle is large, the effective nonlinear optical constant (d_{eff}) becomes small. Therefore, it is preferable to use the LBO crystal at a high temperature by providing a temperature control mechanism to the LBO crystal. This can reduce the phase matching angle, that is, the constant referred to above (d_{eff}) can be increased, and the generation efficiency of the eighth-harmonic wave can be improved.

[0093]

It is a matter of course, that the wavelength conversion portion shown in Fig. 6 is a mere example, and the arrangement of the wavelength conversion portion in the present invention is not limited to it. For example, ultraviolet light having a wavelength of 157nm, which is the same as the F_2 laser, may be generated by performing a tenth-harmonic generation on the fundamental wave having a wavelength of 1.57μm emitted from the outgoing end of the fiber-bundle 173 using the nonlinear optical crystal.

[0094]

Referring back to Fig. 2, the beam monitor mechanism 164 is made up of a Fabry-Perot etalon (hereinafter also referred to as "etalon element") and an energy monitor consisting of a photoconversion element such as a photodiode (neither is shown in Figs.). The beam incident

on the etalon element structuring the beam monitor mechanism 164 passes through the etalon element with a transmittance that corresponds to the frequency difference of the resonance frequency of the etalon element and the frequency of the incident beam. And the output signals of the photodiode and the like, which detect the intensity of the transmitted beam, are sent to the laser controller 16B. The laser controller 16B performs a predetermined signal processing on the output signals, and obtains information related to the optical properties of the incident beam on the beam monitor mechanism 164, to be precise, on the etalon element (to be concrete, information such as the center wavelength of the incident beam and the width of the wavelength (spectral half-width)). And the information related to the optical properties is sent to the main controller 50 realtime.

[0095]

The frequency characteristic of the transmitted light intensity that the etalon element generates is affected by the temperature or pressure of atmosphere, and in particular, the resonance frequency (resonance wavelength) is temperature dependent. Therefore, it is important to study the temperature dependence of the resonance wavelength in order to precisely control the center wavelength and spectral half-width of the laser beam oscillated from the laser light source 160A based on

the detection results of the etalon element. In the embodiment, the temperature dependence of the resonance wavelength is measured in advance, and the measurement results are stored as a temperature dependence map in the memory 51 (refer to Fig. 1) serving as a storage unit, which is arranged with the main controller 50. And, the main controller 50 gives instructions to the laser controller 16B to positively control the temperature of the etalon element within the beam monitor mechanism 164, so that the resonance wavelength (detection reference wavelength) maximizing the transmittance of the etalon element precisely coincides with the set wavelength in cases such as absolute wavelength calibration of the beam monitor mechanism 164.

[0096]

In addition, the output of the energy monitor structuring the beam monitor mechanism 164 is sent to the main controller 50, and the main controller 50 detects the energy power of the laser beam based on the output of the energy monitor and controls the light amount of the laser beam oscillated from the DFB semiconductor laser 160A via the laser controller 16B or turns off the DFB semiconductor laser 160A when necessary. In the embodiment, however, as will be described later on, the light amount control (exposure amount control) is usually performed mainly by the light amount controller 16C, by controlling the peak power or frequency of the pulse

light emitted from the EOM160C or by on/off control of the light emitted from each fiber amplifier structuring the light amplifying portion 161. Accordingly, the main controller 50 controls the laser controller 16B in the manner described above when the energy power of the laser beam changes greatly for some reason.

[0097]

The absorption cell 165 is an absolute wavelength source for absolute wavelength calibration of the oscillation wavelength of the DFB semiconductor laser 160A, in other words, is the absolute wavelength source for absolute wavelength calibration of the beam monitor mechanism 164. In the embodiment, since the DFB semiconductor laser 160A having the oscillation wavelength of 1.544μm is used as the light source, an isotope of acetylene having dense absorption lines in the wavelength band around the wavelength of the DFB semiconductor laser 160A is used as the absorption cell 165.

[0098]

As will be described later on, in the case of selecting intermediate waves of the wavelength conversion portion 163 (such as the second-harmonic wave, the third harmonic wave, and the fourth harmonic wave) or light which wavelength has been converted with, or in alternate of the fundamental wave as the light for monitoring the wavelength of the laser beam, the absorption cell that

has dense absorption lines around the wavelength of the intermediate wave can be used. For example, in the case of selecting the third-harmonic wave as the light for monitoring the wavelength of the laser beam, iodine molecules that have dense absorption lines around the wavelength of 503nm to 530nm can be used as the absorption cell. The appropriate absorption line of the iodine molecules can be chosen, and the wavelength of the absorption line can be determined as the absolute wavelength.

[0099]

In addition, the absolute wavelength source is not limited to the absorption cell, and the absolute wavelength light source may also be used.

[0100]

The laser controller 16B detects the center wavelength and the wavelength width (spectral half-width) of the laser beam based on the output of the beam monitor mechanism 164, and feedback controls the temperature control (and current control) of the DFB semiconductor laser 160A so that the center wavelength becomes a desired value (set wavelength). In the embodiment, it is possible to control the temperature of the DFB semiconductor laser 160A in the unit of 0.001°C.

[0101]

In addition, the laser controller 16B switches the output of the DFB semiconductor 160A between the pulse

output and the continuous output and controls the output interval and pulse width during pulse output, as well as control the oscillation of the DFB semiconductor laser 160A so as to compensate the output variation of the pulse light, in accordance with instructions from the main controller 50.

[0102]

In this manner, the laser controller 16B stabilizes the oscillation wavelength to a constant wavelength, as well as finely adjust the output wavelength. On the contrary, the laser controller 16B may also adjust the output wavelength of the DFB semiconductor laser 160A by positively changing the oscillation wavelength in accordance with instructions from the main controller 50.

[0103]

For example, with the former control, generation or change in aberration (image forming characteristics) of the projection optical system PL due to change in wavelength can be prevented, thus change in image characteristics (optical properties such as image quality) during pattern transfer can be avoided.

[0104]

In addition, with the latter control, variation in image forming characteristics (such as aberration) of the projection optical system PL occurring due to the difference in altitude and pressure between the place where the exposure apparatus was made and adjusted and

where the exposure apparatus is arranged (delivered) or the difference in the environment (atmosphere of the clean room), can be cancelled out, and the start-up time of the exposure apparatus at the delivery site can be reduced. Furthermore, with the latter control, change in aberration, projection magnification, and focal position of the projection optical system PL due to the irradiation of the illumination light for exposure and atmospheric change can also be canceled out during the operation of the exposure apparatus, and it becomes possible to transfer the pattern image onto the substrate in the best image forming state.

[0105]

The light amount controller 16C has the following functions: stabilizing the amplification of the fiber amplifiers at each channel at each amplifying stage, by performing feedback control on the drive current of each pumping semiconductor laser (178 and 174) based on the output of the photoconversion elements 180 and 181 that detect the light emitted from the fiber amplifiers 168_n and 171_n within the light amplifying portion 161; and stabilizing the desired ultraviolet output by performing feedback control on the drive current of at least either the pumping semiconductor laser 178 or the pumping semiconductor laser 174 and feeding back the predetermined light intensity expected to each amplifying stage, based on the output signal of the photoconversion

element 182, which detects the light split by the beam splitter along the wavelength conversion portion 163.

[0106]

Furthermore, in the embodiment, the light amount controller 16C has the following functions.

[0107]

That is, the light amount controller 16C has the functions of:

① Controlling the average light output of the bundle in total by performing individual on/off control on the output of the fiber of each channel making up the bundle-fiber 173, in other words, the output of each optical path 172_n, in accordance with instructions from the main controller 50 (hereinafter referred to as the "first function" for the sake of convenience);

② Controlling the average light output (output energy) per unit time of each channel in the light amplifying portion 161, in other words, the intensity of the light emitted per unit time from each optical path 172_n, by controlling the frequency of the pulse light emitted from the EOM160C in accordance with instructions from the main controller 50 (hereinafter referred to as the "second function" for the sake of convenience); and

③ Controlling the average light output (output energy) per unit time of each channel in the light amplifying portion 161, in other words, the intensity of the light emitted per unit time from each optical path 172_n, by

controlling the peak power of the pulse light emitted from the EOM160C in accordance with instructions from the main controller 50 (hereinafter referred to as the "third function" for the sake of convenience).

[0108]

According to the first function of the light amount controller 16C, the average light output (light amount) of the whole bundle is controllable by $1/128^{th}$ of the maximum light output (by around 1% and under). That is, the dynamic range can be set at a wide range of 1 - 1/128. Since each optical path 172_n is made up of the same structuring material, designwise, the light output of the optical path 172_n is supposed to be equal, therefore light amount control by $1/128^{th}$ is to have good linearity.

[0109]

In addition, with the embodiment, the wavelength conversion portion 163 is arranged to perform wavelength conversion on the output of the light amplifying portion 161, that is, on the output of the fiber-bundle 173. The output of the wavelength conversion portion 163 is proportional to the output of each optical path 172_n, that is, to the number of fibers of the fiber amplifier 171_n in an on state. Therefore, in principle, a linear light amount control by $1/128^{th}$ of the maximum light output (by around 1% and under) is possible.

[0110]

However, in actual, possibilities are high that the

output of each optical path 172_n is dispersed or the wavelength conversion efficiency in respect to each optical path 172_n is dispersed due to manufactural errors and the like. Therefore, the output dispersion of each optical fiber (optical path 172_n), the output dispersion due to the wavelength conversion efficiency dispersion in respect to the output of each optical fiber and the like are measured in advance. And based on the measurement results, a first output intensity map, which is a map on intensity of light output from the wavelength conversion portion 163 corresponding to the on/off state of the light output of each optical fiber (a conversion table of output intensity corresponding to the fiber group in the "on" state), is made, and stored in the memory 51 arranged along with the main controller 50.

[0111]

And, the light amount controller performs light amount control based on the set light amount provided from the main controller 50 and the intensity map described above, when performing the light amount control related to the first function.

[0112]

In addition, the light amount controller 16C controls the frequency of the pulse light emitted from the EOM160C in the second function described above by changing the frequency of the rectangular wave (voltage pulse) impressed on the EOM160C. Since the frequency of the

pulse light emitted from the EOM160C coincides with the frequency of the voltage pulse impressed on the EOM160C, the frequency of the pulse light emitted is to be controlled by controlling the impressed voltage.

[0113]

In the embodiment, as is previously described the frequency of the rectangular wave impressed on the EOM160C is 100kHz. For example, if the frequency is increased to 110kHz, then the number of the light pulse per unit time increases by 10%, and the delay portion 167 sequentially divides each pulse to the total of 128 channels, from channel 0 to 127, in the same manner as described above. As a consequence, the pulse light per unit time in each channel increases by 10%, and if the light energy per light pulse is the same, that is, the peak power of the pulse light is constant, then, the output light intensity (light amount) of each optical path 172_n per unit time also increases by 10%.

[0114]

In addition, in the embodiment, the wavelength conversion portion 163, which converts the wavelength of the emitted light from each channel of the light amplifying portion 161, is arranged, and the light amount of the light emitted per unit time of the wavelength conversion portion 163 is proportional to the frequency of the output pulse of each channel, if the peak power is constant. Accordingly, the light amount control of the

second function is control with excellent linearity.

[0115]

However, in general the amplification gain of the fiber amplifier has input light intensity dependence, so if the frequency of the output light of the EOM160C is changed, there may be cases where the input light intensity of the fiber amplifiers 168_n and 171_n changes, and as a result, the peak power of the pulse light emitted from the fiber amplifiers 168_n and 171_n may also change. Accordingly, it is not always possible in actuality to obtain the linearity as described above. Thus, in the embodiment, the input frequency intensity dependence of the output of fiber amplifiers is measured in advance. And based on this measurement, the second output intensity map, which is a map on intensity of output from (each channel of) the light amplifying portion 161 corresponding to the frequency of the pulse light input to the light amplifying portion 161 (a conversion table of output intensity of the light amplifying portion 161, corresponding to the frequency of light emitted from the EOM) is made, and stored into the memory 51.

[0116]

And, when the light amount controller 16C performs the light amount control in the second function, the light amount control is performed based on the set light amount provided from the main controller 50 and the

second output intensity map described above.

[0117]

In addition, the light amount controller 16C controls the peak power of the pulse light emitted from the EOM160 in the third function described above, by controlling the peak intensity of the voltage pulse impressed on the EOM160C. This is because the peak power of the emitted light from the EOM160C is dependent on the peak intensity of the voltage pulse impressed on the EOM160C.

[0118]

However, as is described earlier, the amplifier gain of the fiber amplifier has input light intensity dependence, therefore, if the peak intensity of the pulse light emitted from the EOM160C is changed, there may be cases where the input light intensity of the fiber amplifiers 168_n and 171_n changes, and as a result, the peak power of the pulse light emitted from the fiber amplifiers 168_n and 171_n may also change. It is possible, to suppress the change in peak power by designing the fiber amplifiers 168_n and 171_n appropriately, however, this may reduce the light output efficiency and other performances of the fiber amplifiers.

[0119]

So, in the embodiment, the input pulse peak intensity dependence of the output of fiber amplifiers is measured in advance. And based on this measurement, the third output intensity map, which is a map on intensity of

light output from (each channel of) the light amplifying portion 161 corresponding to the peak intensity of the pulse light input to the light amplifying portion 161 (a conversion table of output pulse light intensity of the light amplifying portion 161, corresponding to the peak intensity of light emitted from the EOM) is made, and stored into the memory 51. The third output intensity map may be an ultraviolet intensity map, which serves as the wavelength conversion portion output.

[0120]

And, when the light amount controller 16C performs the light amount control in the third function, the light amount control is performed based on the set light amount provided from the main controller 50 and the third output intensity map described above.

[0121]

It is possible to arrange another EOM for transmittance control other than the EOM160C at the output side of the DFB semiconductor laser 160A. And the transmittance of the EOM can be changed by changing the voltage impressed to the EOM, so as to change the energy emitted from the light amplifying portion and wavelength conversion portion per unit time.

[0122]

As can be seen from the description so far, in the second and third function of the light amount controller 16C, finer light amount control of the emitted light from

the light source unit 16 is possible when compared with the first function. On the other hand, in the first function, the dynamic range can be set at a wider level, when compared with the second and third function.

[0123]

Therefore, in the embodiment, on the exposure that will be described later on, rough adjustment of the exposure amount is to be performed according to the first function of the light amount controller 16C, and fine adjustment is to be performed using the second and third function. This will be referred to later in the description.

[0124]

Other than the controls above, the light amount controller 16C also controls the start/stop of the pulse output in accordance with instructions from the main controller 50.

[0125]

The polarization adjustment unit 16D controls the polarization properties of the optical components arranged prior to the optical fiber amplifier 171_n, so as to perform circular polarization on the light emitted from the optical fiber amplifier 171_n. In the case the doped fiber of the optical fiber amplifier 171_n has a structure almost cylindrically symmetric and is relatively short in length, circular polarization on the light emitted from the optical fiber amplifier 171_n can

also be performed, by performing circular polarization on the light incident on the optical fiber amplifier 171_n.

[0126]

Components such as the relay light optical fiber (not shown in Figs.) are arranged as the optical components arranged prior to the optical fiber amplifier 171_n. The relay light optical fiber optically connects each elements of the light amplifying portion 161, and as the method of controlling polarization properties of the relay light optical fiber and the like, for example, there is a way of applying anisotropic dynamic stress to the relay optical fiber. This method is used in the embodiment.

[0127]

The relay optical fiber has a cylindrically symmetric refractive index distribution in general, however, in the case anisotropic dynamic stress is applied anisotropic stress is generated in the relay optical fiber, which creates an anisotropic refractive index distribution. By controlling the amount of the anisotropic refractive index distribution generated, the polarization properties of the relay light optical fiber can be controlled.

[0128]

In addition, the variation amount of the refractive index distribution due to stress generated in the relay fiber and the polarization properties of other optical components depend on temperature. Therefore, the

polarization adjustment unit 16D controls the circumferential temperature of the relay optical fiber and the like so that the temperature is constant, so that it is possible to maintain the circular polarization that has been performed.

[0129]

The polarization properties of the relay optical fiber, or in other words, the refractive index distribution, can be controlled without the temperature control described above, by monitoring the polarized state of the light at a position further downstream of the relay optical fiber and performing control based on the monitored results.

[0130]

Referring back to Fig. 1, the illumination optical system 12 comprises: a beam shaping optical system 18; a fly-eye lens system 22 serving as an optical integrator (a homogenizer); an illumination system aperture stop plate 24; a beam splitter 26; a first relay lens 28A; a second relay lens 28B; a fixed reticle blind 30A; a movable reticle blind 30B; a mirror M for deflecting the optical path; a condenser lens 32; and the like.

[0131]

The beam shaping optical system 18 shapes the sectional shape of the light in the ultraviolet region (hereinafter referred to as "laser beam") LB generated by converting the wavelength of light emitted from the light

source unit 16 at the wavelength conversion portion 163 so that it is efficiently incident on the fly-eye lens system 22, which is arranged downstream of the optical path of the laser beam LB. The beam shaping optical system 18, for example, is made up of a cylindrical lens or a beam expander (neither is shown in Figs.).

[0132]

The fly-eye lens system 22 is arranged on the optical path of the laser beam LB emitted from the beam shaping optical system 18, and forms a planar light source, that is, a secondary light source, which consists of many light source images (point light sources), to illuminate the reticle R with a uniform illuminance distribution. The laser beam emitted from the secondary light source, is also referred to as "exposure light IL", in this description.

[0133]

In the vicinity of the emitting surface of the fly-eye lens 22, the illumination system aperture stop plate 24, which is made of a plate-shaped member, is arranged. On the illumination system aperture stop plate 24, a plurality of aperture stops are arranged at substantially equal angular intervals. The aperture stops may have an ordinary circular aperture, or it may have a small circular-shaped aperture for reducing the σ-value, which is a coherence factor. It may also have a ring-shaped aperture for ring-shaped illumination, or a plurality of

apertures (for example, four apertures) of which each central position differ from the optical axis position for modified illumination (in Fig. 1, only two of these aperture stops are shown). The illumination system aperture stop plate 24 is rotated by a driving unit 40 such as a motor, controlled by the main controller 50, and either aperture stop is selectively chosen to be set on the optical path of the exposure light IL in correspondence with the reticle pattern.

[0134]

On the optical path of the exposure light IL outgoing from the illumination system aperture stop plate 24, the beam splitter 26, which has a large transmittance and a small reflectance, is arranged. And further downstream on the optical path, the relay optical system, structured of the first relay lens 28A and the second relay lens 28B is arranged, with the fixed reticle blind 30A and the movable reticle blind 30B arranged in between.

[0135]

The fixed retile blind 30A is arranged on a surface slightly defocused from the conjugate plane relative to the pattern surface of the reticle R, and a rectangular opening is formed to set the illumination area 42R on the reticle R. In addition, close to the fixed retile blind 30A, the movable reticle blind 30B is arranged. The movable reticle blind 30B has an opening portion, which position and width is variable in the scanning direction,

and by further restricting the illumination area 42R via the movable reticle blind 30B during the start and completion of the scanning exposure, exposure on unnecessary portions can be avoided.

[0136]

On the optical path of the exposure light IL further downstream of the second relay lens 28B structuring the relay optical system, the deflection mirror M is arranged to reflect and bend the exposure light IL that has passed through the second relay lens 28 toward the reticle R, and on the optical path beyond the mirror M, the condenser lens 32 is arranged.

[0137]

Furthermore, on either side of the optical path vertically bent at the beam splitter 26 within the illumination optical system 12, an integrator sensor 46 and a reflection light monitor 47 are respectively arranged. As the integrator sensor 46 and the reflection light monitor 47, a silicon PIN type photodiode is used, which is sensitive to light in the far ultraviolet region and the vacuum ultra violet region and also has high response frequency to detect the pulse emission of the light source unit 16. Or, it is possible to use a semiconductor photodetection element having a GaN crystal as the integrator sensor 46 and the reflection light monitor 47.

[0138]

With the structure described above, the incident surface of the fly-eye lens system 22, the arrangement surface of the movable reticle blind 30B, and the pattern surface of the reticle R, are arranged optically conjugated with each other. And, the light source surface formed on the outgoing side of the fly-eye lens system 22 and the Fourier transform surface of the projection optical system PL (exit pupil surface) are arranged optically conjugated with each other, forming a Koehler illumination system.

[0139]

The operation of the illumination optical system 12 having the structure described above will now be briefly described. The laser beam LB, pulse-emitted from the light source unit 16, is incident on the beam shaping optical system 18, and the sectional shape of the laser beam LB is shaped so that it is efficiently incident on the fly-eye lens system 22, which is arranged further downstream. The laser beam LB, is then incident on the fly-eye lens system 22, and the secondary light source is formed on the focal plane of the emitting side of the fly-eye lens system 22 (the pupil surface of the illumination optical system 12). The exposure light IL outgoing from the secondary light source, then passes through one of the aperture stops on the illumination system aperture stop plate 24, and reaches the beam splitter 26, which has a large transmittance and a small

reflectance. The exposure light IL, which passes through the beam splitter 26 proceeds to the first relay lens 28A, and then passes through the rectangular opening of the fixed reticle blind 30A and the movable reticle blind 30B. After passing through the movable reticle blind 30B, the exposure light IL passes through the second relay lens 28B, and the optical path is then bent vertically downward by the mirror M. The exposure light IL, then passes through the condenser lens 32 and illuminates the rectangular illumination are 42R on the reticle R held on the reticle stage RST with a uniform illuminance distribution.

[0140]

Meanwhile, the exposure light IL, which is reflected off the beam splitter 26, passes through the condenser lens 44 and is photo-detected by the integrator sensor 46. And the photoelectric conversion signal of the integrator sensor 46 is sent to the main controller 50 as the output DS (digit/pulse) via a peak hold circuit and an A/D converter (not shown in Figs.). The relative coefficient of the output DS of the integrator sensor 46 and the illuminance (exposure amount) of the exposure light IL on the surface of the wafer W is stored in the memory 51 serving as a storage unit arranged with the main controller 50.

[0141]

In addition, the exposure light, which illuminates

the illumination area 42R on the reticle R and is reflected off the pattern surface of the reticle (the lower surface in Fig. 1), proceeds backward in the opposite direction as before through the condenser lens 32 and the relay lens system, and is reflected off the beam splitter 26 and photo-detected by the reflection light monitor 47 via the condenser lens 48. In addition, in the case the Z tilt stage 58 is arranged below the projection optical system PL, the exposure light IL, which has passed through the pattern surface of the reticle, is reflected off the projection optical system PL and the surface of the wafer W (or the surface of the fiducial mark plate FM, which will be described later), and proceeds backward in the order of the projection optical system PL, the reticle R, the condenser lens 32, and the relay lens system, and is reflected off the beam splitter 26 to be photo-detected by the reflection light monitor 47 via the condenser lens 48. Also, although the surface of each optical element arranged in between the beam splitter 26 and the wafer W has a lens coating to prevent reflection, an extremely small amount of the exposure light IL is reflected on the surface, and the reflection light is also photo-detected by the reflection light monitor 47. The photoconversion signals of the reflection monitor 47 are supplied to the main controller 50 via the peak hold circuit and the A/D converter (not shown in Figs.). The reflection monitor 47 is mainly used

to measure the reflectance of the wafer W in the embodiment. The reflection monitor 47 may also be used to measure the transmittance of the reticle R in advance.

[0142]

As the fly-eye lens system, for example, a double fly-eye lens system, which details are disclosed in, Japanese Patent Laid Open No. 01-235289 (the corresponding U.S. Patent No. 5,307,207), and in Japanese Patent Laid Open No. 07-142354 (the corresponding U.S. Patent No. 5,534,970), may be employed to structure a Koehler illumination system.

[0143]

In addition, a diffractive optical element may be used with the fly-eye lens system 22. In the case of using such a diffractive optical element, the light source unit 16 and the illumination optical system 12 may be connected with the diffractive optical element arranged in between. That is, in correspondence with each fiber of the fiber-bundle 173, the diffractive optical element on which the diffractive element is formed can be arranged in the beam shaping optical system 18, and the laser beam emitted from each fiber can be diffracted so that the beams are superimposed on the incident surface of the fly-eye lens system 22. In this example, the output end of the fiber-bundle 173 may be arranged on the pupil surface of the illumination optical system. In this case, however, the intensity distribution (in other words,

the shape and size of the secondary light source) on the pupil surface varies due to the first function (partial on/off to reduce total output), and may not be the most suitable shape and size for the reticle pattern. Thus, it is preferable to use the diffractive optical element and the like described earlier, to superimpose the laser beam from each fiber on the pupil surface of the illumination optical system or on the incident surface of the optical integrator.

[0144]

In any case, in the embodiment, even if the distribution of the portion that emits light from the fiber-bundle 173 varies, uniform illuminance distribution on both the pattern surface (object surface) of the reticle R and the surface (image plane) of the wafer W can be sufficiently secured due to the first function of the light amount controller 16C, referred to earlier.

[0145]

The reticle R is mounted on the reticle stage RST, and is held on the stage by vacuum chucking (not shown in Figs.). The reticle stage RST is finely drivable within a horizontal surface (XY plane), as well as scanned in the scanning direction (in this case, the Y direction, being the landscape direction in Fig. 1) within a predetermined stroke range by the reticle stage driving portion 49. The position and rotational amount of the reticle stage RST during scanning, is measured via the movable mirror 52R

fixed to the reticle stage RST by the laser interferometer 54R arranged externally, and the measurement values of the laser interferometer 54R is supplied to the main controller 50.

[0146]

The material used for the reticle R depends on the wavelength of the exposure light IL. That is, in the case of using exposure light with the wavelength of 193nm, synthetic quartz can be used. In the case of using exposure light with the wavelength of 157nm, however, the reticle R needs to be made of fluorite, fluorine-doped synthetic quartz, or crystal.

[0147]

The projection optical system PL is, for example, a double telecentric reduction system, and is made up of a plurality of lens elements 70a, 70b, ……, which have a common optical axis in the Z-axis direction. In addition, as the projection optical system PL, a projection optical system having a projection magnification β of, for example, 1/4, 1/5, or 1/6, is used. Therefore, when the illumination area 42R on the reticle R is illuminated with the exposure light IL as is described earlier, the pattern formed on the reticle R is projected and transferred as a reduced image by the projection magnification β with the projection optical system PL on the slit-shaped exposure area 42W on the wafer W, which surface is coated with the resist (photosensitive agent).

[0148]

In the embodiment, of the lens elements referred to above, a plurality of lens elements are respectively capable of moving independently. For example, the lens element 70a arranged topmost and closest to the reticle stage RST is held by a ring-shaped supporting member 72, and this ring-shaped supporting member 72 is supported at three points by expandable driving elements such as piezo elements 74a, 74b, and 74c (74c in depth of the drawing is not shown in Fig. 1), and is also connected to the barrel portion 76. The three points on the periphery of the lens element 70a is movable independently in the optical axis direction AX of the projection optical system PL by the driving elements 74a, 74b, and 74c. That is, translation operation of the lens element 70a can be performed along the optical axis AX in accordance with the deviation amount of the driving elements 74a, 74b, and 74c, as well as tilt operation of the lens element 70a in respect to the plane perpendicular to the optical axis AX. And the voltage provided to the driving elements 74a, 74b, and 74c is controlled by the image forming characteristics correction controller 78 based on instructions from the main controller 50, and thus the deviation amount of the driving elements 74a, 74b, and 74c is controlled. Also, in Fig. 1, the optical axis AX of the projection optical system PL refers to the optical axis of the lens element 70b and the other lens elements

(omitted in Fig. 1) fixed to the barrel portion 76.

[0149]

In addition, in the embodiment, the relation between the vertical movement amount of the lens element 70a and the variation in magnification (or in distortion) is obtained in advance by experiment. The relation is stored in a memory within the main controller 50, and the magnification (or distortion) correction is performed by calculating the vertical movement amount of the lens element 70a from the magnification (or distortion) corrected by the main controller 50 on correction, and by providing instructions to the image forming characteristics correction controller 78 to drive the driving elements 74a, 74b, and 74c to correct the magnification (or distortion). Further, optical calculation values can be used in the relation between the vertical movement amount of the lens element 70a and the variation in magnification. In this case, the experimental process to obtain the relation between the vertical movement amount of the lens element 70a and the variation in magnification can be omitted.

[0150]

As is described earlier, the lens element 70a closest to the reticle R is movable. The lens element 70a is selected, because the influence on the magnification and distortion characteristics is greater compared with the other lens elements, however, any lens element may be

arranged movable alternately of the lens element 70a to adjust the interval between lenses, if identical conditions can be satisfied.

[0151]

Also, by moving at least one optical element besides the lens element 70a, other optical properties such as the field curvature, astigmatism, coma, and spherical aberration can be adjusted. Moreover, a sealed chamber may be arranged in between specific lens elements near the center in the optical axis direction of the projection optical system PL, and an image forming characteristics correction mechanism can be arranged to adjust the magnification of the projection optical system PL by adjusting the pressure of the gas inside the sealed chamber with a pressure adjustment mechanism such as a bellows pump. Or, alternately, for example, an aspherical lens may be used as a part of the lens element structuring the projection optical system PL, and the aspherical lens may be rotated. In this case, correction of the so-called rhombic distortion becomes possible. Or, the image forming characteristics correction mechanism may have the structure of a plane-parallel plate arranged within the projection optical system PL, which can be tilted and rotated.

[0152]

Furthermore, in the case of using the laser beam with the wavelength of 193m as the exposure light IL,

materials such as synthetic quartz and fluorite can be used for each lens element (and the plane-parallel plate) structuring the projection optical system PL. In the case of using the laser beam with the wavelength of 157nm, however, only fluorite is used as the material for the lenses and the like.

[0153]

The XY stage 14 is driven two-dimensionally, in the Y direction, which is the scanning direction, and in the X direction, which is perpendicular to the Y direction (the direction perpendicular to the page surface of Fig. 1), by the wafer stage driving portion 56. The Z tilt stage 58 is mounted on the XY stage 14, and on the Z tilt stage 58, the wafer W is held via a wafer holder 61 (not shown in Figs.) by vacuum chucking and the like. The Z tilt stage 58 has the function of adjusting the position of the wafer W in the Z direction by for example, three actuators (piezo elements or voice coil motors), and also the function of adjusting the tilting angle of the wafer W in respect to the XY plane (image plane of the projection optical system PL). In addition, the position of the XY stage 14 is measured via the movable mirror 52W fixed on the Z tilt stage 58 by the laser interferometer 54W, which is externally arranged, and the measurement values of the laser interferometer 54W is sent to the main controller 50.

[0154]

As the movable mirror, in actual, an X movable mirror that has a reflection plane perpendicular to the X-axis and a Y movable mirror that has a reflection plane perpendicular to the Y-axis are arranged, and in correspondence with these mirrors, interferometers for an X-axis position measurement, Y-axis position measurement, and rotation (including yawing amount, pitching amount, and rolling amount) measurement are respectively arranged. In Fig. 1, however, these are representatively shown as the movable mirror 52W and the laser interferometer 54W.

[0155]

In addition, on the Z tilt stage 58 close to the wafer W, an irradiation amount monitor 59, which has a photo-detecting surface arranged at the same height as that of the exposure surface on the wafer W, is arranged to detect the light amount of the exposure light IL that has passed through the projection optical system PL. The irradiation amount monitor 59 has a housing that is one size larger than the exposure area 42W, extends in the X direction, and is rectangular in a planar view. And in the center portion of this housing, an opening is formed, which has a slit-shape almost identical to the exposure area 42W. This opening is actually made by removing a portion of a light shielding film formed on the upper surface of the photo-detection glass made of materials such as synthetic quartz, which forms the ceiling surface of the housing. And, immediately below the opening via

the lens, an optical sensor having a photodetection element such as the silicon PIN type photodiode is arranged.

[0156]

The irradiation amount monitor 59 is used to measure the intensity of the exposure light IL irradiated on the exposure area 42W. The light amount signals according to the amount of light received by the photodetection element structuring the irradiation amount monitor 59 is sent to the main controller 50.

[0157]

The optical sensor does not necessarily have to be arranged within the Z tilt stage 58, and it is a matter of course that the optical sensor may be arranged exterior to the Z tilt stage 58. In this case, the illumination beam relayed by the relay optical system may be guided to the optical sensor via an optical fiber or the like.

[0158]

On the Z tilt stage 58, the fiducial mark plate FM used when performing operations such as reticle alignment, which will be described later, is arranged. The fiducial mark plate FM is arranged so that the height of the surface is almost the same as that of the surface of the wafer W. On the surface of the fiducial mark plate FM, fiducial marks for reticle alignment, baseline measurement, and the like, are formed.

[0159]

Also, it is omitted in Fig. 1 to avoid complication in the drawing, in actual, the exposure apparatus 10 comprises a reticle alignment system to perform reticle alignment.

[0160]

When alignment is performed on the reticle R, first of all, the main controller 50 drives the reticle stage RST and the XY stage 14 via the reticle stage driving portion 49 and the wafer stage driving portion 56 so that the fiducial mark for reticle alignment on the fiducial mark plate FM is set within the exposure area 42W having a rectangular shape and the positional relationship between the reticle R and the Z tilt stage 58 is set so that the reticle mark image on the reticle R almost overlaps the fiducial mark. In this state, the main controller 50 picks up the image of both marks using the reticle alignment system, processes the pick-up signals, and calculates the positional shift amount of the projected image of the reticle mark in respect to the corresponding fiducial mark in the X direction and the Y direction.

[0161]

In addition, it is also possible to obtain the focus offset and leveling offset (the focal position of the projection optical system PL, image plane tilt, and the like) based on information on contrast, which is included

in the detection signals (picture signals) of the projected image of the fiducial marks obtained as a consequence of the reticle alignment described above.

[0162]

Also, in the embodiment, when the reticle alignment is performed, the main controller 50 also performs baseline measurement of the off-axis alignment sensor on the wafer side (not shown in Figs.) arranged on the side surface of the projection optical system PL. That is, on the fiducial mark plate FM, fiducial marks for baseline measurement that are arranged in a predetermined positional relationship in respect to the fiducial marks for reticle alignment are formed. And when the positional shift amount of the reticle mark is measured via the reticle alignment system, the baseline amount of the alignment sensor, in other words, the positional relationship between the reticle projection position and the alignment sensor, is measured by measuring the positional shift of the fiducial marks for baseline measurement in respect to the detection center of the alignment sensor via the alignment sensor on the wafer side.

[0163]

Furthermore, as is shown in Fig. 1, with the exposure apparatus 10 in the embodiment, it has a light source which on/off is controlled by the main controller 50, and a multiple focal position detection system (a focus

sensor) based on the oblique incident method is arranged, consisting of an irradiation optical system 60a which irradiates light from an incident direction in respect to the optical axis AX to form multiple pinhole or slit images toward the image forming plane of the projection optical system PL, and of an photodetection optical system 60b which photo-detects the light reflected off the surface of the wafer W. By controlling the tilt of the plane-parallel plate arranged within the photodetection optical system 60b (not shown in Figs.) in respect to the optical axis of the reflected light, the main controller 50 provides an offset corresponding to the focal change of the projection optical system PL to the focal detection system (60a, 60b) and performs calibration. With this operation, the image plane of the projection optical system PL within the exposure area 42W coincides with the surface of the wafer W within the range (width) of the depth of focus. Details on the structure of the multiple focal position detection system (a focus sensor) similar to the one used in the embodiment, are disclosed in, for example, Japanese Patent Laid Open No. 06-283403.

[0164]

The main controller 50 performs automatic focusing and automatic leveling by controlling the Z position of the Z tilt stage 58 via the driving system (not shown in Figs.) so that the defocus becomes zero, based on the

defocus signals such as the S-curve signals from the photodetection optical system 60b.

[0165]

The reason for arranging the plane-parallel plate within the photodetection optical system 60b to provide an offset to the focal detection system (60a, 60b) is, for example, that when the lens element 70a is vertically moved for magnification correction the focus also changes, and when the projection optical system PL absorbs the exposure light IL the position of the image forming plane changes with the change in the image forming characteristics of the projection optical system PL, and accordingly, it is necessary in such cases to make the focusing position of the focal detection system coincide with the position of the image forming plane of the projection optical system PL by providing an offset to the focal detection system. Therefore, in the embodiment, the relationship between the vertical movement amount of the lens element 70a and the focus variation is also obtained in advance by experiment, and is stored in the memory within the main controller 50. Calculated values may be used for the relationship between the vertical movement amount of the lens element 70a and the focus variation. And, as for the automatic leveling, it may be performed only in the non-scanning direction, which is perpendicular to the scanning direction, without being performed in the scanning direction.

[0166]

The main controller 50 is structured including a so-called microcomputer (or workstation) made up of components such as a CPU (central processing unit), a ROM (Read Only Memory), a RAM (Random Access Memory), and the like. Other than performing various controls described so far, the main controller 50 controls, for example, the synchronous scanning of the reticle R and the wafer W, the stepping operation of the wafer W, the exposure timing, and the like so that the exposure operation is performed accurately. In addition, in the embodiment, the main controller 50 has control over the whole apparatus, besides controls such as controlling the exposure amount on scanning exposure as will be described later, and calculating the variation amount of the image forming characteristics of the projection optical system PL and adjusting the image forming characteristics of the projection optical system PL based on the calculation via the image forming characteristics correction controller 78.

[0167]

To be more precise, for example, on scanning exposure, the main controller 50 respectively controls the position and velocity of the reticle stage RST and the XY stage 14 via the reticle stage driving portion 49 and the wafer stage driving portion 56 so that the wafer W is scanned via the XY stage 14 at the velocity $V_W=\beta\cdot V$ (β is the

projection magnification from the reticle R to the wafer W) in the -Y direction (or +Y direction) in respect to the exposure area 42W, in synchronous with the reticle R scanned via the reticle stage RST at the velocity V_R=V in the +Y direction (or -Y direction), based on the measurement values of the laser interferometers 54R and 54W. Also, when performing stepping operations, the main controller 50 controls the position of the XY stage 14 via the wafer stage driving portion 56, based on the measurement values of the laser interferometer 54W.

[0168]

The exposure sequence of the exposure apparatus 10 in the embodiment will be described next, when exposure on predetermined slices (N slices) of wafers W is performed to transfer the reticle pattern onto the wafer W, while mainly referring to the controls performed by the main controller 50.

[0169]

First, the main controller 50 loads the reticle R subject to exposure on the reticle stage RST, using the reticle loader (not shown in Figs.).

[0170]

Next, the reticle alignment described earlier is performed, using the reticle alignment system, as well as the baseline measurement.

[0171]

Then, the main controller 50 instructs the wafer

carriage system (not shown in Figs.) to exchange the wafer W. By the instructions, the wafer is exchanged (or simply loaded when there are no wafers on the stage) by the wafer carriage system and the wafer delivery mechanism (not shown in Figs.) on the XY stage 14. When this is completed, a series of operations in the alignment process are performed, such as the so-called search alignment and fine alignment (EGA and the like). Since the wafer exchange and the wafer alignment are performed likewise, as is performed with the well-acknowledged exposure apparatus, the more detailed description is omitted here.

[0172]

Next, based on the above alignment results and the shot map data, the reticle pattern is transferred onto a plurality of shot areas on the wafer W based on the step-and-scan method by repeatedly performing the operation of moving the wafer W to the starting position for scanning to expose each shot area on the wafer W and the scanning exposure operation. During this scanning exposure, in order to provide the target exposure amount to the wafer W, which is decided in accordance with exposure conditions and the resist sensitivity, the main controller 50 gives instructions to the light amount controller 16C while monitoring the output of the integrator sensor 46. And according to the instructions, in addition to the rough adjustment of the exposure

amount based on the first function, the light amount controller 16C controls the frequency and the peak power of the laser beam (pulse ultraviolet light) from the light source 16 based on the second and third functions, thus performs fine adjustment of the exposure amount.

[0173]

In addition, the main controller 50 controls the illumination system aperture stop plate 24 via the driving unit 40, and furthermore, controls the opening/closing of the movable reticle blind 30B in synchronous with the operation information of the stage system.

[0174]

When exposure on the first wafer W is completed, the main controller 50 instructs the wafer carriage system (not shown in Figs.) to exchange the wafer W. Wafer exchange is thus performed, by the wafer carriage system and the wafer delivery mechanism (not shown in Figs.) on the XY stage 14, and after the wafer exchange is completed, search alignment and fine alignment is performed likewise as is described above to the wafer that has been exchanged. In addition, in this case, the main controller 50 calculates the irradiation change of the image forming characteristics (including the change in focus) of the projection optical system PL from the start of exposure on the first wafer W, based on the measurement values of the integrator sensor 46 and the

reflection light monitor 47. The main controller 50 then provides instruction values to the image forming characteristics correction controller 78 to correct the irradiation change, as well as provide an offset to the photodetection optical system 60b. Also, the main controller 50 calculates the atmospheric pressure change of the image forming characteristics of the projection optical system PL based on the measurement values of the atmospheric pressure sensor 77, and provides instruction values to the image forming characteristics correction controller 78 to correct the irradiation change, as well as provides an offset to the photodetection optical system 60b.

[0175]

And, in the manner described earlier, the reticle pattern is transferred onto the plurality of shot areas on the wafer W based on the step-and-scan method.

[0176]

The rough adjustment of the exposure amount (light amount) described earlier may be precisely controlled in the accuracy of 1% and under to the exposure amount set value, by performing test emission prior to the actual exposure.

[0177]

The dynamic range of the rough adjustment of the exposure amount in the embodiment can be set within the range of 1 - 1/128. The dynamic range normally required,

however, is around 1 - 1/7 in typical, therefore, the number of channels (the number of optical fibers) which light output should be turned on may be controlled in between 128 - 18. In this manner, in the embodiment, rough adjustment of the exposure amount in line with the difference of the resist sensitivity and the like of each wafer can be accurately performed by the exposure amount control individually turning on/off the light output of each channel.

[0178]

In addition, since the light amount control based on the second and third function by the light amount controller 16C has the features of quick control velocity and high control accuracy, it is possible to satisfy the following control requirements required in the current exposure apparatus without fail.

[0179]

Accordingly, for light amount control, the light amount controller 16C only has to perform light amount control based on at least either the second function or the third function.

[0180]

In addition, with the exposure apparatus 10 in the embodiment, as a matter of course, the exposure amount control can be performed by combining the light amount control based on either the second or third function by the light amount controller 16C and the scanning velocity.

[0181]

The exposure conditions of the wafer W is changed in accordance with the reticle pattern to be transferred onto the wafer W, such as changing the intensity distribution of the illumination light (that is, the shape and size of the secondary light source) on the pupil surface of the illumination optical system, or inserting/removing the optical filter which shields the circular area having the optical axis as its center around the pupil surface of the projection optical system PL. The illuminance on the wafer W changes by these changes in exposure conditions, however, the illuminance on the wafer W also changes with the change in the reticle pattern. This is due to the difference in the occupied area by the shielding area (or the transmitting area) of the pattern. Therefore, when the illuminance changes due to the change of the exposure conditions and/or of the reticle pattern, it is preferable to control at least either the frequency or the peak power referred to above so as to provide the suitable exposure amount to the wafer (resist). On this control, in addition to adjusting at least either the frequency or the peak power, the scanning velocity of the reticle and the wafer may also be adjusted.

[0182]

As have been described above, with the light source unit related to the present embodiment, when the

polarization adjustment unit 16D performs circular polarization on the polarized state of the light beams emitted from each of the optical fiber amplifier 171_n, linearly polarizes all the light beams in the same polarized direction by one quarter-wave plate 162, and emits the beams. Accordingly, the light which has been efficiently converted by the wavelength conversion portion 163 arranged downstream can be generated, by appropriately setting the optical axis direction of the quarter wave plate 162. In addition, since the polarization direction conversion unit has an extremely simple arrangement having one quarter-wave plate 162, the size of the overall light source unit 16 can be reduced.

[0183]

In addition, with the light source unit 16 related to the present embodiment, because the plurality of light beams emitted from the optical fiber amplifier 171_n is converted to a linearly polarized beam in the same polarized direction, a plurality of linearly polarized beams each having high intensity and the same polarized direction can be obtained as the emitted light from the quarter-wave plate 162. Consequently, the light amount of the emitted light can be increased in the light source unit 16 as a whole.

[0184]

With the light source unit related to the present embodiment, since the plurality of light beams incident

on the optical fiber amplifier 171_n are respectively a pulse train, the light amount of the emitted light can be controlled with high precision in the light source unit 16 as a whole, by adjusting the repetition frequency of the light pulse or the pulse height in each pulse train.

[0185]

In addition, with the light source unit 16 related to the present embodiment, since the plurality of light beams incident on the optical fiber amplifier 171_n can respectively be a light beam that has been amplified by the optical fiber amplifier 167_n before entering the optical fiber amplifier 171_n, by the light amplification of multiple stages by the multiple optical fiber amplifiers 167_n and 171_n, the light amount of the emitted light can be increased in the light source unit 16 as a whole.

[0186]

In addition, with the light source unit 16 related to the present embodiment, since polarization adjustment is performed by applying anisotropic stress to the relay light optical fiber which is the optical component arranged upstream of the optical fiber amplifier 171_n and controlling polarization properties, even in the case the polarization adjustment of impressing stress and the like is not adequate for the doped fiber of the optical fiber amplifier 171_n, circular polarization can be performed on the polarized state of the plurality of light beams

incident on the quarter-wave plate 162 without adversely affecting performances and functions of the light source unit 16.

[0187]

In addition, with the light source unit 16 according to the present embodiment, since the doped fibers of the optical fiber amplifier 171_n are bundled almost in parallel to one another, the space where the doped fibers occupy can be made small and the photodetection area on the quarter-wave plate 162 can be small, therefore, the size of the light source unit 16 can be reduced.

[0188]

Further, with the light source unit 16 related to the present embodiment, since the light emitted from the optical fiber amplifier 171_n is light in the infrared region (the wavelength: around 1547nm), and the light emitted from the wavelength conversion unit 163 is converted into light in the ultraviolet region (the wavelength: around 193.4nm), the ultraviolet light suitable for transferring fine patterns can be efficiently generated.

[0189]

With the exposure apparatus 10 related to the present embodiment, since the light source unit 16 is used which efficiently generates ultraviolet light suitable for transferring fine patterns, the pattern can be efficiently transferred onto the wafer W.

[0190]

In the embodiment above, the polarization adjustment unit 16D performs circular polarization adjustment on the emitted light of the optical fiber amplifier 171_n. However, in the case the polarization is an elliptical polarization, which adjustment is similar to the circular polarization, instead of the quarter-wave plate 162, a combination of a half-wave plate that rotates the plane of polarization and a quarter-wave plate which is optically connected in series to the half-wave plate can be used to convert the plurality of beams emitted from the optical fiber amplifier 171_n to a linear polarized beam in the same polarized direction. Either of the half-wave plate or the quarter-wave plate may be arranged upstream, in the series connection.

[0191]

In addition, in the embodiment above, the light incident on the quarter-wave plate 162 is the emitted light from the optical fiber amplifier 171_n, however, a plurality of beams emitted from a plurality of optical fiber for optical waveguiding may be incident on the quarter-wave plate 162.

[0192]

Also, in the embodiment above, the case has been described when the light amplifying portion 161 has optical paths of 128 channels. However, the number of optical paths may be any number, and the number can be

determined depending on the product in which the light source unit related to the present invention is applied, such as, the specification (illuminance on the wafer) and optical properties required in the exposure apparatus, that is, the transmittance of the illumination optical system and the projection optical system, the conversion efficiency of the wavelength conversion portion, and the output of the optical path. Even in such a case, the frequency control of the pulse light emitted from the optical modulator referred to earlier, and light amount, exposure amount control by peak power control can be suitably applied.

[0193]

Furthermore, the wavelength of the ultraviolet light is set almost the same as that of the ArF excimer laser in the embodiment above, however, the set wavelength may be of any wavelength, and the oscillation wavelength of the laser light source 160A, the structure of the wavelength conversion portion 163, and the magnification of the harmonic wave may be decided according to the set wavelength. As an example, the set wavelength may be set in accordance with the design rule (such as the line width and pitch) of the pattern to be transferred onto the wafer, moreover, on deciding the set wavelength, the exposure conditions and the type of reticle (whether the reticle is the phase shift type or not) previously referred to may be considered.

[0194]

In the embodiment above, to control the oscillation wavelength of the laser light source 160A, the laser beam is monitored by the beam monitor mechanism 164 arranged immediately after the laser light source 160A. The present invention, however, is not limited to this, and as is shown in Fig. 5 in dotted lines, the laser beam may be separated within the wavelength conversion portion 163 (or downstream in the wavelength conversion portion 163), and may be monitored by the beam monitor mechanism 183, which is similar to the beam monitor mechanism 164. And, the main controller 50 detects whether the wavelength conversion is performed accurately based on the monitoring results of the beam monitor mechanism 183, and based on the detection results may feedback control the laser controller 16B. Naturally, the monitoring results of both beam monitor mechanisms may be used to perform oscillation wavelength control of the laser light source 160A.

[0195]

In addition, with the embodiment above, the fly-eye lens system 22 is used as the optical integrator (homogenizer), however, instead of this arrangement, the rod integrator may be used. In the illumination optical system that uses the rod integrator, the rod integrator is arranged so that its outgoing surface is almost conjugate with the pattern surface of the reticle R,

therefore, for example, the fixed reticle blind 30A and the movable reticle blind 30B may be arranged in the vicinity of the outgoing surface of the rod integrator.

[0196]

In addition, although it is not specifically referred to in the description above, with the exposure apparatus which performs exposure using the wavelength of 193nm and under as in the embodiment, measures such as filling or creating a flow of clean air that has passed through a chemical filter, dry air, N_2 gas, or inert gas such as helium, argon, or krypton in the passage of the exposure beam, or vacuuming the passage of the exposure beam, need to be taken.

[0197]

The exposure apparatus in the embodiment above is made by assembling various subsystems including elements defined in the claims of the present application so as to keep a predetermined mechanical precision, electrical precision, and optical precision. In order to ensure these areas of precision, prior to and after the assembly, adjustment is performed on various optical systems to attain a predetermined optical precision, adjustment is performed on various mechanical systems to attain a predetermined mechanical precision, and adjustment is performed on various electrical systems to attain a predetermined electrical precision, respectively. The process of incorporating various subsystems into an

exposure apparatus includes mechanical connection of various subsystems, by wiring electrical circuits, piping pressure circuits, and the like. Obviously, before the process of incorporating various subsystems into an exposure apparatus, the process of assembling the respective subsystems is performed. After the process of assembling various subsystems into the exposure apparatus is completed, total adjustment is performed to ensure preciseness in the overall exposure apparatus. The exposure apparatus is preferably made in a clean room in which temperature, degree of cleanliness, and the like are controlled.

[0198]

Also, in the embodiment above, the case has been described when the light source unit is used in a scanning exposure apparatus based on the step-and-scan method, however, the light source unit related to the present invention can be applied in units besides the exposure apparatus, for example, in a laser repair unit used to cut off a part of a circuit pattern (such as a fuse) formed on a wafer. In addition, the light source unit in the present invention can also be applied to inspection units using visible light or infrared light. And in this case, there is no need to incorporate the wavelength conversion portion into the light source unit. That is, the present invention is also effective with not only the ultraviolet laser unit, bus also with the laser

unit that generates a fundamental wave in the visible light region or the infrared light region having no wavelength conversion portion. In addition, the present invention is not limited to the scanning exposure apparatus based on the step-and-scan method, and can be suitably applied to the static exposure type, for example, to the exposure apparatus based on the step-and-repeat method (such as the stepper). Furthermore, the present invention can also be applied to the exposure apparatus based on the step-and-stitch method, to the mirror projection aligner, and the like.

[0199]

The projection optical system and the illumination optical system referred to above in the embodiment, are mere examples, and it is a matter of course that the present invention is not limited to these. For example, the projection optical system is not limited to the refraction optical system, and a reflection system made up of only reflection optical elements or a reflection refraction system (a catadioptric system) that is made up of both the reflection optical elements and the refraction optical elements may be employed. With the exposure apparatus using vacuum ultraviolet light (VUV light) having the wavelength of around 200 nm and under, the use of the reflection refraction system can be considered as the projection optical system. As the projection optical system of the reflection/refraction

type, for example, a reflection/refraction system having a beam splitter and concave mirror as reflection optical elements, which details are disclosed in, for example, Japanese Patent Laid Open No.08-171054 and Japanese Patent Laid Open No. 10-20195 can be used. Or, the reflection/refraction system having a concave mirror and the like as reflection optical elements without using any beam splitter, which details are disclosed in, for example, Japanese Patent Laid Open No.08-334695 and Japanese Patent Laid Open No. 10-3039 can also be used.

[0200]

Besides the systems referred to above, the reflection/refraction system in which a plurality of refracting optical elements and two mirrors (a concave mirror serving as a main mirror, and a sub-mirror serving as a back-mirror forming a reflection plane on the side opposite to the incident plane of a refracting element or a parallel flat plate) are arranged on the same axis, and an intermediate image of the reticle pattern formed by the plurality of refracting optical elements is re-formed on the wafer by the main mirror and the sub-mirror, may be used. The details of this system is disclosed in, U.S. Patent No. 5,488,229, and the Japanese Patent Laid Open No. 10-104513. In this reflection/refraction system, the main mirror and the sub-mirror are arranged in succession to the plurality of refracting optical elements, and the illumination light passes through a part of the main

mirror and is reflected on the sub-mirror and then the main mirror. It then further proceeds through a part of the sub-mirror and reaches the wafer.

[0201]

Of course, the present invention can be suitably applied to not only the exposure apparatus used to manufacture a semiconductor device, but also to the exposure apparatus used to manufacture a display including the liquid crystal display device that transfers the device pattern onto a glass plate, to the exposure apparatus used to manufacture a thin-film magnetic head that transfers the device pattern onto a ceramic wafer, to the exposure apparatus used to manufacture a pick-up device (such as a CCD).

[0202]

[EFFECT OF THE INVENTION]

As have been described above, with the light source unit according to the present invention, after the polarization adjustment unit orderly arranges the polarized state of a plurality of light beams emitted from the plurality of optical fibers, the polarized direction conversion unit converts all light beams that have passed through the plurality of optical fibers into a plurality of linearly polarized light beams that have the same polarized direction, and accordingly the plurality of light beams having the same polarized direction can be obtained with a simple arrangement.

[0203]

In addition, with the exposure apparatus according to the present invention, since the light source unit of the present invention which efficiently generates ultraviolet light suitable for transferring fine patterns is used, as the generation unit of exposure beam, the pattern can be efficiently transferred onto the substrate.

[BRIEF DESCRIPTION OF THE DRAWING]

[FIG. 1]

Fig. 1 is a schematic view showing the configuration of the exposure apparatus of the embodiment in the present invention.

[FIG. 2]

Fig. 2 is a block diagram showing the internal structure of the light source unit in Fig. 1 with the main control unit.

[FIG. 3]

Fig. 3 is a schematic view showing the arrangement of the light amplifying portion in Fig. 2.

[FIG. 4]

Fig. 4 is a sectional view showing the bundle-fiber formed by bundling the output end of the fiber amplifiers arranged at a final stage that structure the light amplifying portion.

[FIG. 5]

Fig. 5 is a schematic view showing the fiber

amplifiers structuring the light amplifying portion in Fig. 2 and its neighboring portion, with a part of the wavelength conversion portion.

[FIG. 6]

Fig. 6 is a view showing an arrangement example of a wavelength conversion portion in Fig. 2.

[DESCRIPTION OF REFERENCED LETTERS/NUMERALS]

10	Exposure apparatus
16	Light source unit
16D	Polarization adjustment unit
162	Quarter-wave plate (Polarized direction conversion unit)
163	Wavelength conversion portion (Wavelength conversion unit)
W	Wafer (Substrate)

[DOCUMENT NAME] ABSTRACT

[ABSTRACT]

[PROBLEMS TO BE SOLVED]

To generate a predetermined light while controlling a polarized state in a simple arrangement.

[SOLUTION]

After a polarization adjustment unit 16D orderly arranges a polarized state of a plurality of light beams emitted from a plurality of optical fibers, a polarized direction conversion unit 162 converts all light beams that have passed through the plurality of optical fibers into a plurality of linearly polarized light beams that have the same polarized direction. In this case, the polarized direction of the linear polarization is set to be a polarized direction in which wavelength conversion is efficiently performed with respect to an upstream non-linear optical crystal in a wavelength conversion unit at a later stage. Light having a predetermined wavelength is efficiently obtained, by making a plurality of linearly polarized light beams having the same polarized direction obtained in this manner enter the wavelength conversion unit 163 and performing wavelength conversion.

[DRAWING] FIG. 2

Fig. 1

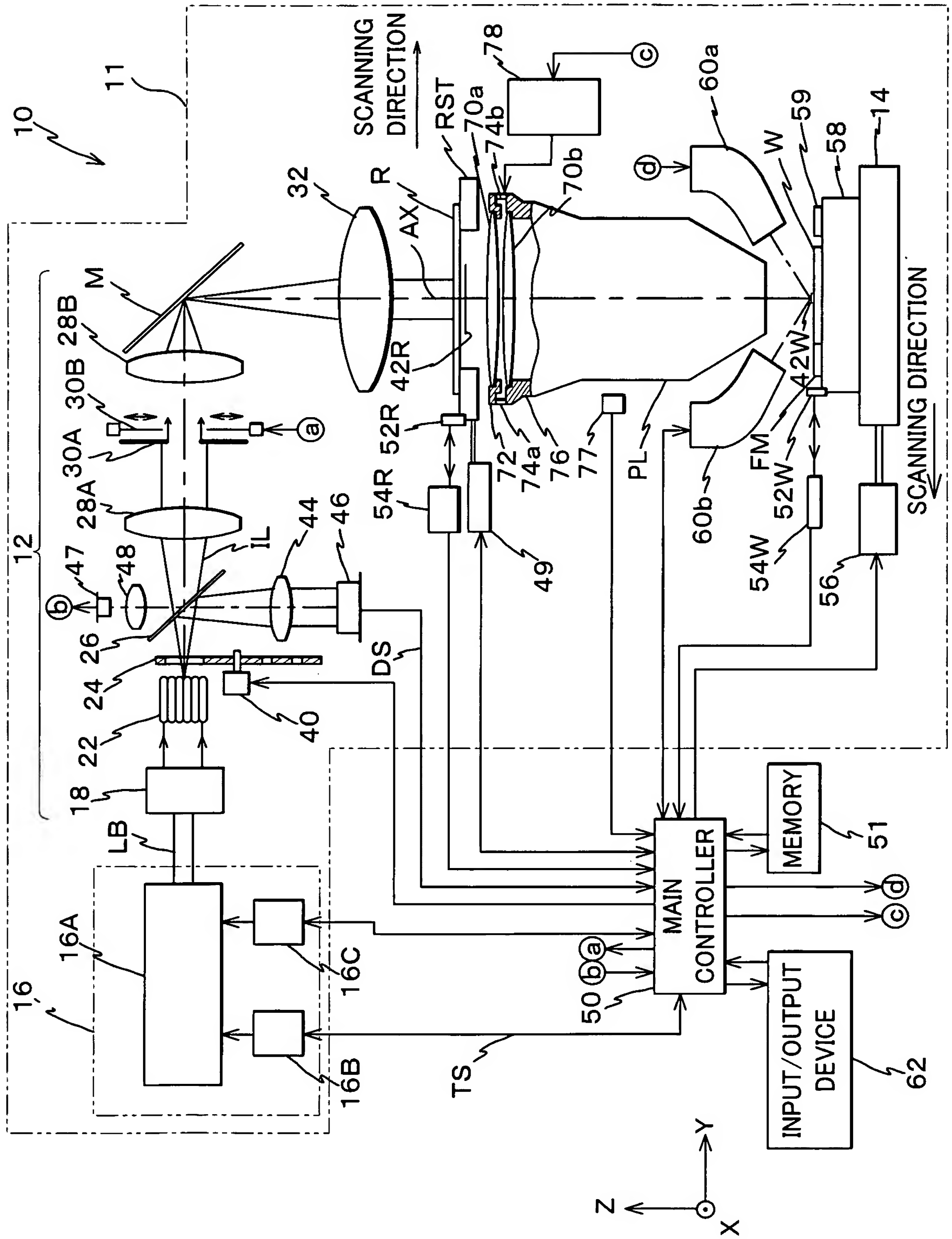

10
11
12
16
16A
16B
16C
LB
18
22
24
26
28A
28B
30A
30B
32
M
R
AX
RST
70a
74b
70b
78
SCANNING DIRECTION
42R
52R
54R
72
74a
76
77
PL
49
40
44
46
47
48
IL
DS
60a
60b
W
59
58
14
42W
FM
52W
54W
56
SCANNING DIRECTION
MAIN CONTROLLER
MEMORY
51
50
TS
INPUT/OUTPUT DEVICE
62
Z
Y
X

Fig. 2

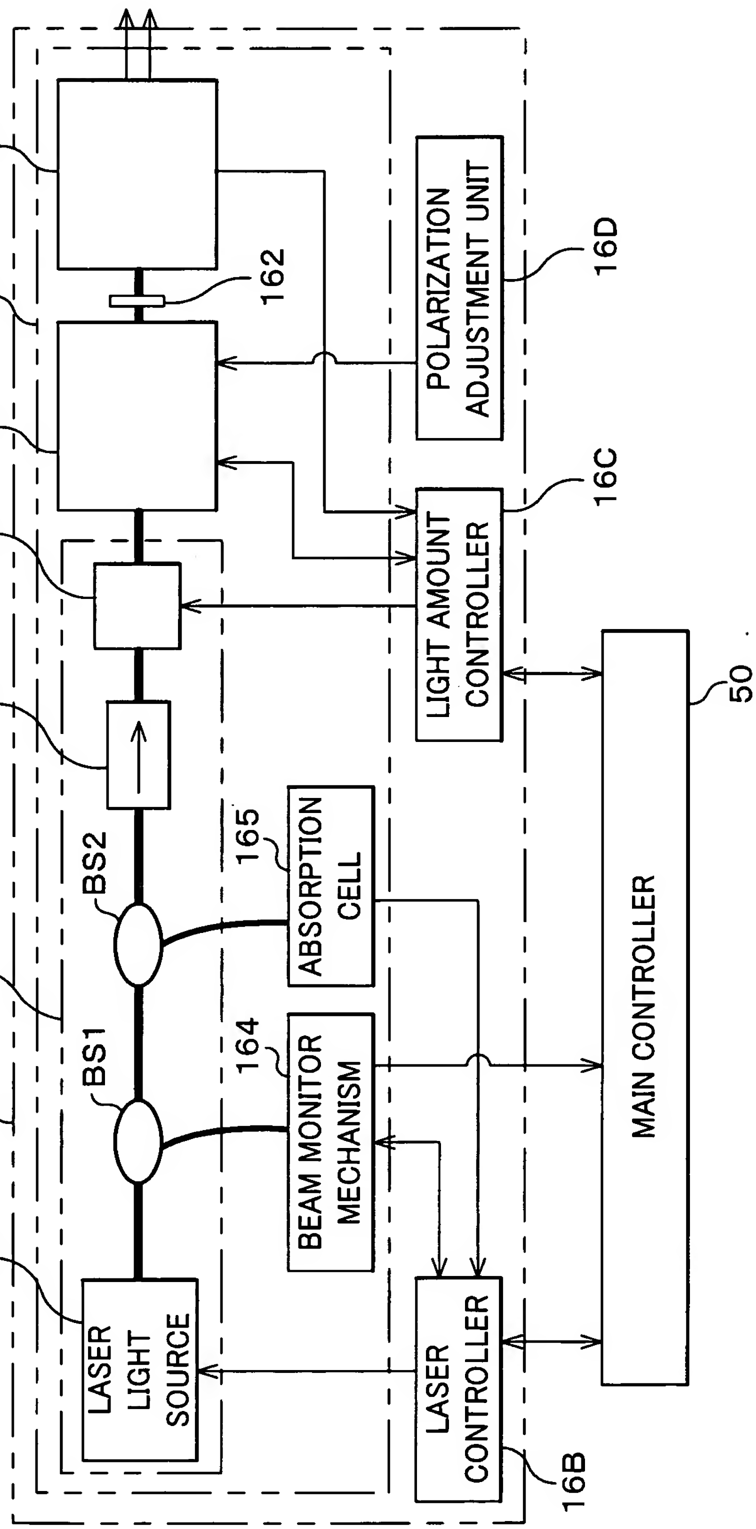

16
16A
16B
16C
16D
160
160A
160B
160C
161
162
163
164
165
50
BS1
BS2
LASER LIGHT SOURCE
BEAM MONITOR MECHANISM
ABSORPTION CELL
LIGHT AMOUNT CONTROLLER
POLARIZATION ADJUSTMENT UNIT
LASER CONTROLLER
MAIN CONTROLLER

Fig. 3

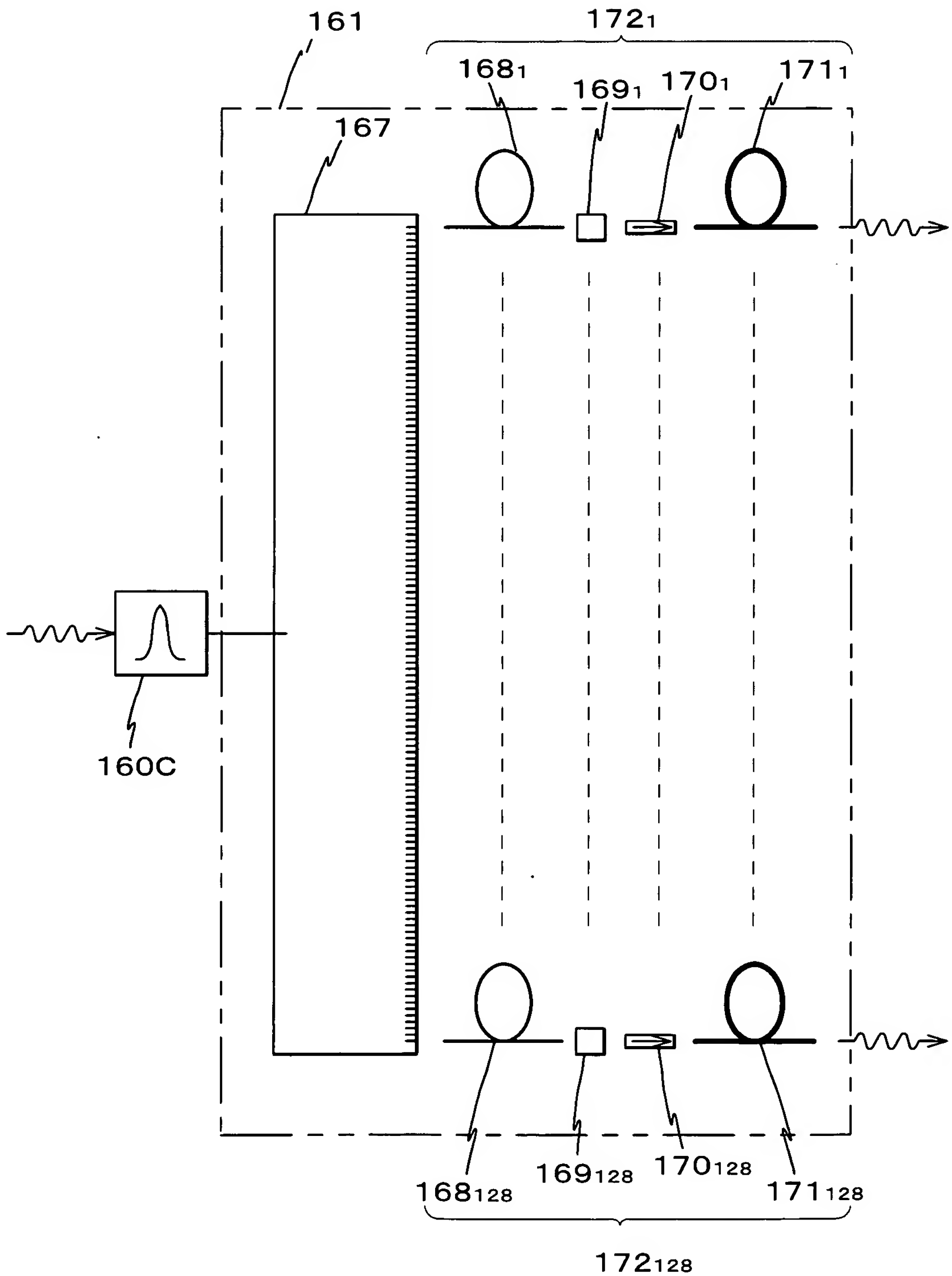

161
172₁
168₁
169₁
170₁
171₁
167
160C
168₁₂₈
169₁₂₈
170₁₂₈
171₁₂₈
172₁₂₈

Fig. 4

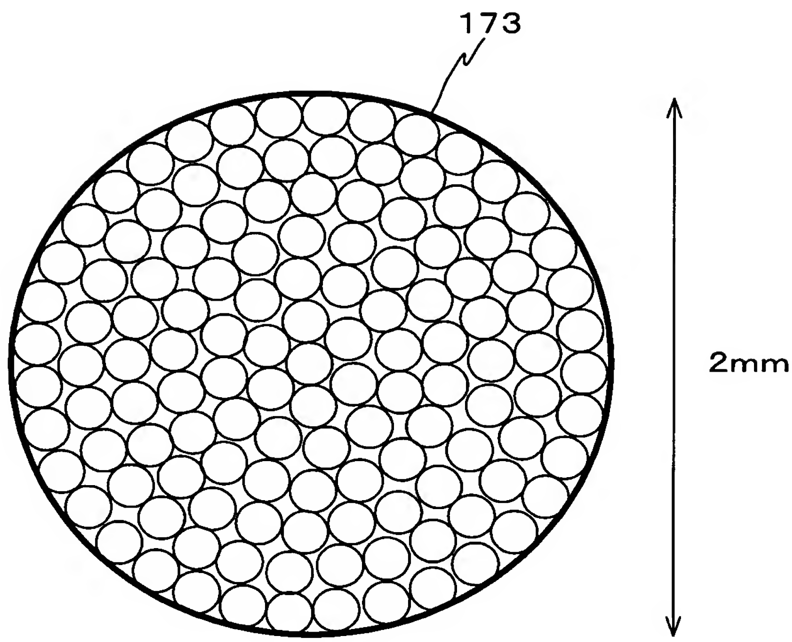


Fig. 5

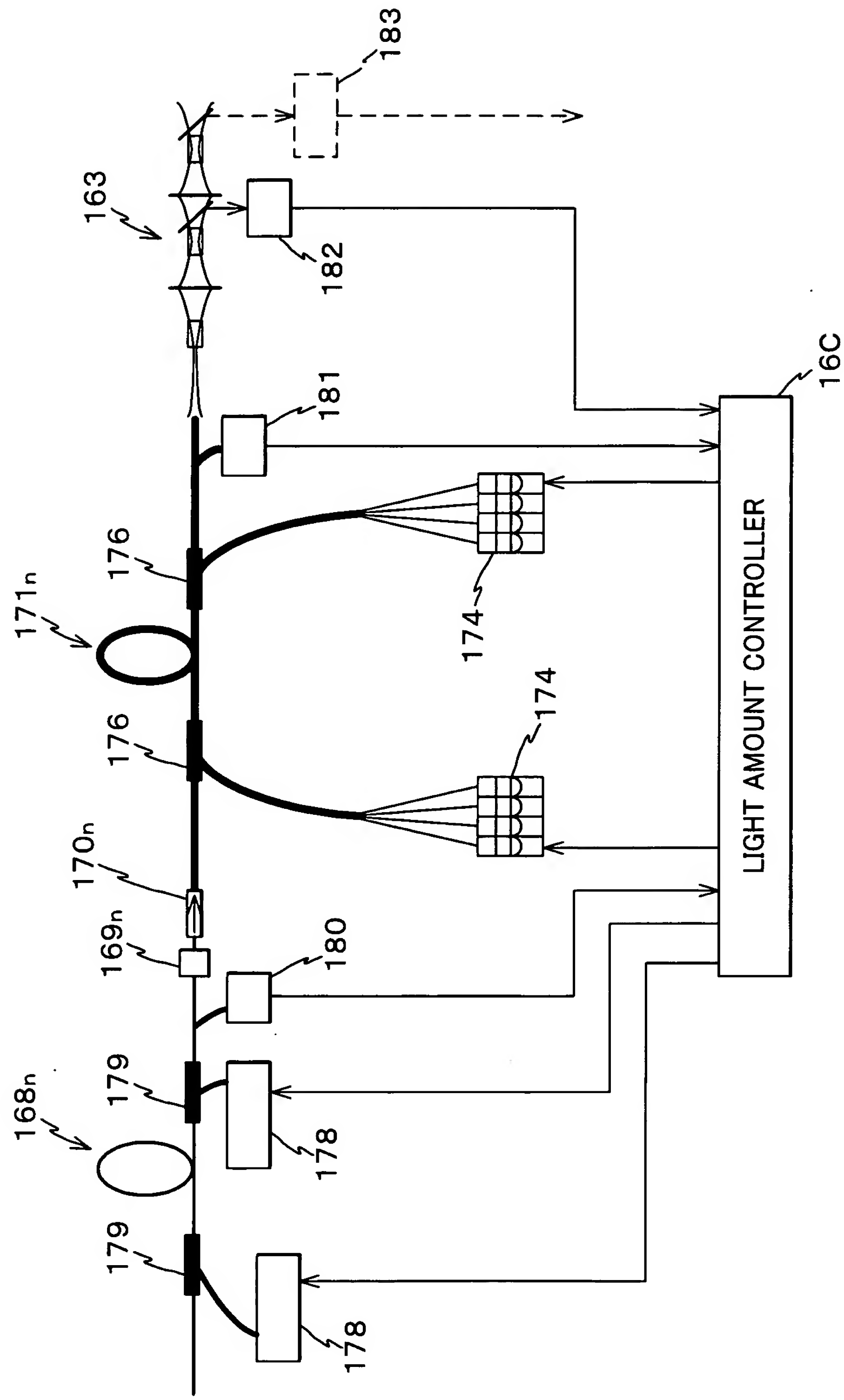
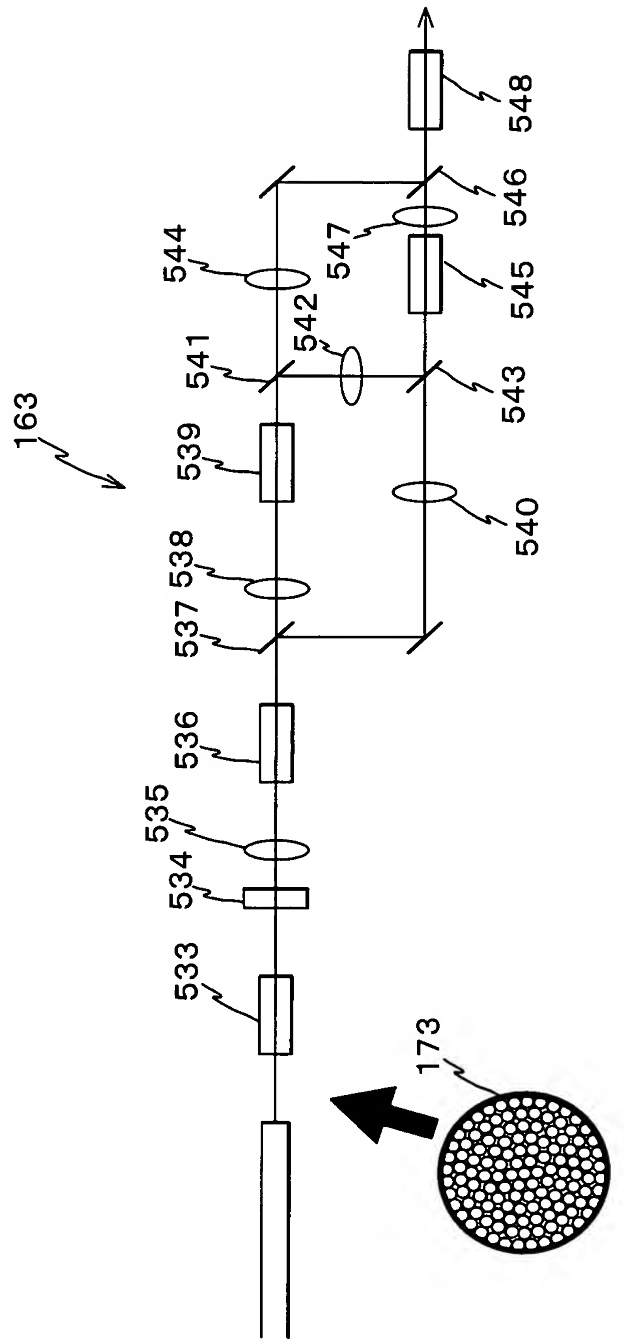

163
183
182
181
16C
176
171n
174
176
174
170n
169n
180
179
168n
178
179
178
LIGHT AMOUNT CONTROLLER

Fig. 6


163
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
173